CHALMERS

A Carbon Footprint Assessment on Construction and Maintenance Operations for the Port of Gothenburg

With emphasis on emission reduction actions

Master's Thesis within the Industrial Ecology programme

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ABSTRACT

Ports are an industry that emits high levels of CO_2 emissions. The purpose of this thesis is to minimise $CO_{2\text{-eq}}$ emissions from the Port of Gothenburg. Four main objectives are used to achieve this purpose. The first is mapping ports, with respect to $CO_{2\text{-eq}}$ emission related activities and reduction targets. Four ports are selected in this report, located in Antwerp, Gothenburg, Los Angeles and Valencia to determine different emission reduction actions. Such actions are a combination of technical development, using same equipment but more efficiently or by change of behaviour. Since no ports have estimated $CO_{2\text{-eq}}$ emissions from construction and maintenance operations before, this report serves as a foundation or inspiration for further development of $CO_{2\text{-eq}}$ calculations. Emissions from construction and maintenance operations are defined as indirect emissions for Gothenburg Port Authority. The second objective is to collect data for the mass of materials and volume of fuels used in construction and maintenance operations for the Port of Gothenburg. Data from year 2013 is used for the collection of used materials and energy related products. The study includes the 22 most extensive projects out of 160 construction and maintenance related projects. The third objective is to calculate and asses $CO_{2\text{-eq}}$ emissions from construction and maintenance operations for the port of Gothenburg. The chosen method for calculating emissions is a carbon footprint assessment and includes a $CO_{2\text{-eq}}$ inventory on construction and maintenance operations at the Port of Gothenburg. The carbon footprint assessment uses emission factors in all calculations. The material and energy related products that contribute the most to $CO_{2\text{-eq}}$ emissions are fossil fuels and concrete. The total $CO_{2\text{-eq}}$ emissions for the 22 projects are approximately 1340 tonnes and in mass approximately 1060 tonnes (excluding fuels). This leads to an increase of 1 % of the current carbon footprint for Gothenburg Port Authority. If using an uncertainty factor with 25 % and including all 160 projects, $CO_{2\text{-eq}}$ emissions during 2013 are estimated to be up to 5600 tonnes, which is an increase with 3 %. The conclusions from the mapping and carbon footprint serve as a foundation for the development of guidelines, which operates as emission reduction potential areas. This is the last objective, including suggestions for guidelines on how to reduce $CO_{2\text{-eq}}$ emissions in port operations.

Key Words: Carbon dioxide emissions, carbon footprint, emission factors, emission scopes

Koldioxidfotavtryck från konstruktions- och underhållsprojekt för Göteborg hamn
Med fokus på åtgärder för minskade utsläpp
Examensarbete inom masterprogrammet *Industrial Ecology*
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SAMMANFATTNING

En industri som släpper ut stora mängder CO_2 är hamnar. Syftet med denna rapport är att minska $CO_{2\text{-ekv}}$ utsläppen från Göteborgs hamn. Denna rapport har fyra mål för att kunna uppnå syftet. Det första målet är att kartlägga hamnar med avseende på $CO2_{\text{-ekv}}$ utsläppsaktiviteter och relaterade åtgärder. De hamnar som kartlagts är belägna i Antwerpen, Göteborg, Los Angeles och Valencia. Åtgärderna som presenteras är en kombination av teknikutveckling, att använda existerande verktyg mer effektivt samt att förändra beteendet hos individer. Ingen hamn har tidigare beräknat utsläpp från konstruktions- eller underhållprojekt. Denna rapport bidrar därför till en grundläggande förståelse eller inspiration för ett fortsatt arbete och utveckling av dessa utsläppsberäkningar. Utsläpp från konstruktions- och underhållsprojekt definieras som indirekta utsläpp för Göteborgs Hamn AB. Det andra målet är att samla in data för den massa av material eller volym av de bränslen som använts i konstruktions- och underhållsprojekten i Göteborg hamn. Inventeringen består av en insamlad mängdförteckning av använt material och energirelaterade produkter under 2013. Inventeringen inkluderar de 22 mest omfattade projekt med avseende på kostnad av totalt 160 projekt inom konstruktion och underhåll av hamnen. Det tredje målet i rapporten är att beräkna $CO2_{\text{-ekv}}$ utsläppen för konstruktions- och underhållsprojekten för Göteborgs hamn. Den valda metoden för beräkningarna är standarden koldioxidfotavtryck. Emissionsfaktorer används i samtliga beräkningar i koldioxidfotavtrycket. Det material och energirelaterade produkter som bidrar mest till $CO_{2\text{-ekv}}$ utsläppen är fossila bränslen och betong. Det totala $CO_{2\text{-ekv}}$ utsläppen från de 22 projekten är ungefär 1340 ton och vikten på det använda materialet är ungefär 1060 ton (vid exkludering av de fossila bränslena). Detta genererar en ökning med 1 % av dagens totala koldioxidfotavtryck för Göteborgs Hamn AB. Vid en beräkning med en osäkerhetsfaktor på 25 % och när samtliga 160 projekt utförda 2013 är inkluderade kan $CO_{2\text{-ekv}}$ utsläppen uppgå till 5600 ton, vilket istället genererar en ökning med 3 %. Slutsatserna från kartläggningen samt koldioxidfotavtrycket bidrar till både en förståelse och en möjlighet till utveckling av de riktlinjer som satts upp. Dessa riktlinjer inkluderas i det fjärde målet i denna rapport vilket är att föreslå riktlinjer som innefattar förbättringsmöjligheter som kan generera lägre utsläpp.

Nyckelord: Emissionsfaktorer, indirekta utsläpp, koldioxidfotavtryck, koldioxidutsläpp

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Göteborg, 2014
Anna Sarbring

Table of content

1. Introduction

In recent decades, the climate debate has increased and the anthropogenic greenhouse gas (GHG) emissions have indicated a strong connection to the effects of global climate change on natural and human systems (IPCC, 2014). There are several indicators of climate change, such as changes in surface temperature, atmospheric water vapour, precipitation, severe events, glaciers, ocean and land ice, and sea level rise (IPCC, 2013). The Intergovernmental Panel on Climate Change (IPCC) has repeatedly indicated the increase in temperature and what consequences to await related to climate change (Richard L et al., 2013). According to the United Nations Framework Convention on Climate Change (UNFCCC), countries should take actions towards GHG emissions reduction to minimise the increase in global average temperature to less than two degrees relative to pre-industrial levels. A study shows that the two degree target can be met with at least fifty-fifty chance if the GHG emissions is reduced by half the amount by 2050 and reduced by 75 % by 2100 compared to the baseline year 2000 (Rogelj et al., 2011). In order to achieve this, it is necessary to stabilize GHG concentrations in the atmosphere and reduce GHG emissions to zero in all countries and sectors as soon as possible. The temperature response will continue, because of the slowly degradation of GHGs in the atmosphere. According to the Organization for Economic Co-operation and Development (OCDE), a stabilization of atmospheric concentrations should be at 450 ppm GHG, which are measured in carbon dioxide equivalents ($CO_{2\text{-eq}}$). This concentration is set as the threshold limit (OCDE, 2011).

During 2013, Sweden emitted 55.7 million tonnes GHGs, which is a reduction by 3 % compared to the previous year and a reduction by 23 % compared to the baseline year 1990 (Naturvårdsverket, 2014). The most common GHG is CO_2 (WPCI, 2010). Globally, most CO_2 emissions occur during fossil fuel combustion and deforestation which are the largest contributors to radiative forcing of the climate system (IPCC, 2007). The emissions thus need to be reduced yearly in all sectors to prevent the climate effects. The transport sector is one of the most contributing sectors and represents nearly one fourth of the annual share of CO_2 emissions (Steven, J.D. et al., 2010). International transport, including ocean shipping and aviation, is among the fastest growing sources of anthropogenic GHG emissions (Vaishnav, P., 2014).

Ports need to work towards good design and environmental management of construction and operational activities (GHD, 2013). Ports have the responsibility and also opportunities to make an effort in reduction of GHG emissions. The transport of goods is essential in global supply chains, which enables the ports to influence a sustainable development and handle large volumes of goods. Measures to reduce GHG emissions can provide both a financial as well as an environmental benefit. One way to achieve this is to assess port's current level of emissions through the concept carbon footprint.

The result from an emission inventory and carbon footprint assessment can identify areas of improvements, for example energy efficiency or improved port operations (Jonas, M. et al., 2010). There are also opportunities to reduce risk and discover competitive advantages. Governments are expected to set new policies and provide additional market-based incentives to facilitate significant reductions in emissions. This makes emission estimations in advance important. By working with emission reduction targets, it creates awareness and knowledge about the direct and indirect emissions as well as interpreting the relation between different activities. It is also a tool for the customers and suppliers in their environmental work. It can include possibilities of international benchmark and exchange of experiences. Choices made early in the planning phase in infrastructure projects have often relevant impacts in energy use and generated emissions (Swedish Transport Administration, 2014b).

This master thesis is performed under the supervision of Gothenburg Port Authority, which operates the Port of Gothenburg. The port is the largest in Scandinavia and around 30 % of the Swedish foreign import passes through the port before it is distributed all over Sweden (Gothenburg Port Authority, 2013). This makes the port important from a product producers' perspective as well as from the national trade market. Gothenburg Port Authority focuses on developing, maintaining and promoting the dock area. Private terminal operators perform the cargo handling at the terminals in the Port of Gothenburg. The task for Gothenburg Port Authority is to create the conditions for the Port of Gothenburg to grow towards sustainability. An important step towards reduction potential of emissions from port operations and development is to calculate the carbon footprint on an annual basis. The inventory presents the port as a proactive organization and can serve as basis for setting additional emission targets. The above mentioned is the background to this thesis and the reason to calculate a carbon footprint for construction and maintenance operations for the Port of Gothenburg.

1.1 Purpose and objectives

The purpose for this thesis is the same as for Gothenburg Port Authority, which is to minimise $CO_{2\text{-eq}}$ emissions. This thesis will lead to a broader foundation, understanding and support towards further work with emission reduction to meet the port's GHG emission targets. It could also simplify for both suppliers and customers, which are working with emission estimations and reduction, by increasing their ability to meet the demand placed upon them.

The thesis has four main objectives to achieve:

- Mapping ports, with respect to $CO_{2\text{-eq}}$ emission related activities and emission reduction targets.

- Collect data for the mass of materials and volume of fuels used in construction and maintenance operations for the Port of Gothenburg.

- Calculate and asses $CO_{2\text{-eq}}$ emissions from construction and maintenance operations for the port of Gothenburg.

- Suggest guidelines for how to reduce $CO_{2\text{-eq}}$ emissions in port operations.

1.2 Delimitations

In Gothenburg Port Authority's current emissions estimations, there are a number of indirect emission sources, which have not been included due to missing data. One is the construction and maintenance operations. This thesis will discuss these operations, including for example terminal surface, quay walls and roads within Gothenburg Port Authority operational area. All operations are performed during 2013. The performed operations are under the control of the department of Infrastructure at Gothenburg Port Authority. 22 projects are selected out of 160 construction and maintenance projects and are called reinvestment projects because of the related high investment costs.

The collected mass and volumes used for materials and fuels do not include rented products or equipment that can be reused. This means for example that scaffolds or hammers are used in several projects and all emissions related to them cannot be directly linked to one project in Port of Gothenburg and are therefore excluded. The fuels used in rented vehicles and equipment are thus included.

The report prioritises the effort on reducing emissions from high impact products and activities. Therefore, some products and activities are excluded from the emission calculations. One example is the personnel travel for the workers to and from the port area which is excluded. Other products of more complex structure, for example batteries, fans and other electrical equipment, are also excluded because of the high uncertainty of related emission data. These also have another lifetime than the construction itself or are in other cases used in several projects. For a more comprehensive description and assumptions about materials, see Section 3.2.

The emission factors are limited to "cradle-to-gate", which means they do not include the waste management step or the transportation to any disposal or recycling facilities. For a more comprehensive description of which phases included in the emission factors, see Section 3.3.

The system will include a $CO_{2\text{-eq}}$ inventory on selected emission source materials and operations. All GHG emissions are converted to $CO_{2\text{-eq}}$ by using characterisation factors. For all factors and included emissions, see Appendix I (IPCC, 2007). The $CO_{2\text{-eq}}$ emissions are only related to the Global Warming Potential indicator and not for example to ecotoxicity, biodiversity or land use. Therefore, additional gases with a possible environmental impact, such as SO_2, NO_x and other substances, are excluded. This is due to lack of data and time limitation for this thesis.

1.3 Method overview

Since this thesis has four objectives, each objective has its own method applied. The mapping of ports is performed as a literature study combined with personal communications. This is summarised in a description section for each of the four selected ports. The data of mass and volumes used are collected from invoices. Emission factors for the used materials, fuels, vehicles and equipment are collected from a literature research and for some materials by contacting the contractors who performed the construction and maintenance operations.

When the emission inventory is completed, the environmental impact is calculated as a carbon footprint, measured in $CO_{2\text{-eq}}$. In the carbon footprint assessment, emission factors are used in the calculations. The result covers the emissions from raw material extraction to the use phase excluding the waste management. The result from the carbon footprint and the mapping are summarised and presented as guidelines, which operates as emission reduction potential areas. The guidelines also sustain the quality of the further work with emissions estimations for the Port of Gothenburg performed by Gothenburg Port Authority.

1.4 Thesis outline

The report begins with a theory chapter, Chapter 2, including general port information, emission scopes, the impact indicator Global Warming Potential, the carbon footprint standard and emission factors. It also includes the description of four ports, Port of Antwerp, Port of Gothenburg, Port of Los Angeles and Port of Valencia. The report continues with Chapter 3, encompassing the methods used for conducting the mapping based on the description of the four ports, the data collection, the carbon footprint calculation and the development of guidelines. The result chapter, Chapter 4, includes the result from mapping, the used mass of material and volumes of fuels, also called energy related products, the result for the carbon footprint assessment and suggestions for guidelines. The report continues with Chapter 5, which is the discussion and finally Chapter 6, comprising of conclusions and ends with Chapter 7 with further recommendations.

2. Theory

This chapter comprises different concepts and applied theory. It starts with general port information and continues with the concepts emission scopes, the indicator Global Warming Potential, carbon footprint standard and emission factors. It includes generally theory about GHG emissions and how to calculate them. Later, the highlights of the environmental work from four ports, called the description of ports, are presented. The description identifies how the ports in Antwerp, Gothenburg, Los Angeles and Valencia have worked with environmental protection and serves as a basis for the outcome and implementation of guidelines, which is presented in the result chapter.

2.1 General port information

A port has many different functions and includes several industries and sectors. Transport through ports, port operations, and industrial activities at ports are contributors to GHG emissions. These sources include for example port administration vehicles, power plants providing power for administration offices, tenant buildings, electrified and fuel-powered cargo handling equipment, ships, harbour craft, trucks, rail locomotives, among others (Vaishnav, P., 2014). A port needs continuous maintenance and development to support its functions. Ports are generally located in sensitive areas. A sensitive area can for example be a nature reserve where nearly no environmental impact can occur. The quality of the air, ground water and biodiversity among others need to be protected. In addition to this, ports cannot cause high levels of noises since it often are located near cities. Some ports are also located near a tourist attraction or serve as one itself, which also makes the surrounding sensitive.

The surrounding environment in a port is often tough and there is a substantial risk for the construction materials to break, which enforces reconstruction. According to Dörrheide[1], the most exposed materials in a port are the ones situated between the water surface (sometimes ice during the winter) and air. The main problem for quays is the chloride penetration from the salt water. Therefore, in exposed areas, a commonly used construction material is stainless steel, because of the resistant properties against chlorides. Another used material is concrete, which can have difficulties with carbonatation. Carbonatation is occurring when CO_2 in the atmosphere is in contact with wet air and forms carbonic acid that reacts with the cement, which decomposes. There is also a continuously mechanical impact on terminal surfaces when vessels are loaded and unloaded. Quay construction can remain for 80 to 100 years, but in general the life time is around 40 years including continuously maintenance. For other activities in the port, see Figure 2-2 and the results from mapping ports in Section 4.1.

2.2 Emission scopes

The Greenhouse Gas Protocol regulates the standard for accounting GHG emissions (Carbon Trust, 2012). The total GHG emissions emitted from a company can be divided into direct and indirect emissions and further into three different groups called “scopes” related to the company activities, see Figure 2-1 (GHG Protocol, 2011). The direct emissions are from sources controlled or owned by the company. The indirect emissions are a consequence of the activities performed by the company but the sources are owned or controlled by another company(s).

[1] Elin Dörrheide, Project Manager Gothenburg Port Authority, personal communication 26 March 2014.

Emission types	Scope	Definition	Examples
Direct emissions	Scope 1	Emissions from operations that are owned or controlled by the reporting company	Emissions from combustion and/ or production in owned or controlled equipment or industry
Indirect emissions	Scope 2	Emissions from the generation of purchased or acquired electricity, steam, heating, or cooling consumed by the reporting company.	Use of purchased electricity, steam, heating or cooling
	Scope 3	All indirect emissions (not included in Scope 2), occuring in the value chain of the reporting company, including up- and downstream emissions	Production or purchased products, transporation of purchased products, or use of sold products

Figure 2-1. The emissions are divided into direct and indirect emissions and into three different scopes, scope 1, scope 2 and scope 3. This is the overview of the scopes including their definition and examples. (Inspired by: GHG Protocol, 2011)

Scope 1 includes the direct emissions under control and operation by the company (WPCI, 2010) and is mandatory to include in GHG inventory according to the Greenhouse Gas Protocol (GHG Protocol, 2011). These emissions could for example come from combustion or from production in owned or controlled equipment or industry. Scope 2 includes the indirect emissions from electricity consumption in the operations of the company and also is mandatory to include in a GHG inventory. The last scope, scope 3 includes the indirect emissions, which are consequences of the activities from the company, but have other emission sources. Scope 3 is not mandatory to include in a GHG inventory according to the Greenhouse Gas Protocol. Several emission sources are included in this scope, such as production or purchased products, transportation of purchased products, or use of sold products. These emissions are also divided into upstream and downstream emissions. Upstream emissions are related to purchased or acquired goods and services. Downstream emissions are related to sold goods and services.

One reason for dividing emissions into scopes is to ensure no double counting follow between different companies. The emissions included in scope 1 and scope 2 are therefore only related to one company. The objective with a complete GHG emissions inventory, including all three scopes, is to enable companies to develop understanding for their environmental impacts in all steps over the value chain. The three scopes include different activities depending on the company and industry. For a more adjust explanation of what the three different scopes include for a port corporation, see Figure 2-2.

Emission types	Scope	Examples - Ports
Direct emissions	Scope 1	Port-Owned Fleet Vehicles (vessels and vehicles), Buildings, Stationary Sources.
Indirect emissions	Scope 2	Purchased Electricity for Port-Owned Buildings and Operations, District Heating by Owned Operations.
	Scope 3	Ships,Trucks, Cargo Handling Equipment, Rail, Harbour Craft, Construction and Maintenance, Port Employee Vehicles, Buildings, Purchased Electricity, Business Travels, Loading fuels, Suppliers, Outsourced activities (IT, Security) etc.

Figure 2-2. Each sector or company include different activities in the three different scopes. These are examples of port activities interpret as direct or indirect in the three scopes. (Inspired by: WPCI, 2010)

2.3 Impact indicator – Global Warming Potential

To estimate the impact on climate change from products or activities, the indicator Global Warming Potential (GWP), equal to the indicator carbon footprint can be used (CALU, 2008). The associated endpoints from global warming are polar melt, soil moisture loss, longer seasons, forest loss/change, and change in wind and ocean patterns (EPA, 2006). To calculate the impact indicators, see Equation 2-1,

$$\textit{Impact Indicators} = \textit{Inventory Data} \times \textit{Characterization Factor} \qquad [2\text{-}1]$$

where the inventory data are the data collected from the activities related to the product or activity. The characterization factor converts inventory data to equivalents in the impact indicator unit, which for GWP are into $CO_{2\text{-eq}}$ (Pandey, D. et al., 2011). The value of the factors depends on the substances' contribution to cause increase of the temperature in the atmosphere. The GWP also depends on the time horizon for the emission, which is in most cases set to 100 years but could also be set to 20 years or 500 years. The definition of GWP for a substance is the ratio between the increased infrared absorption it causes and the increased infrared absorption caused by 1 kg of CO_2 expressed in Equation 2-2 (Baumann, H. & Tillman, A., 2004),

$$GWP_{T,i} = \int a_i \cdot c_i \cdot (t)\, dt \,/ \int a_{CO_2} \cdot c_{CO_2} \cdot (t)\, dt \qquad [2\text{-}2]$$

where a_i [W/m^{2}kg] is the radiative forcing per unit concentration increase of GHG *I*. c_i [kg/m^3] is the concentration of greenhouse gas *i* at time *T* after release and *t* [year] is the time over which the integration is performed. As for GWP, there are more GHGs than CO_2 and the most common are Nitrous oxide (N_2O), Methane (CH_4), Chlorofluorocarbons (CFCs), Hydrochlorofluorocarbons (HCFCs) and Methyl Bromide (CH3Br) (Forster, P. et. al., 2007). For a list of all included GHG and there's characterization factors, see Appendix I. All GHG emissions are summarized as $CO_{2\text{-eq}}$ emissions to provide the impact GWP, expressed as a carbon footprint (Melanta, S. et al., 2013).

2.4 Carbon Footprint Standard

The definition of a carbon footprint refers to the land area that is required to assimilate the total anthropogenic $CO_{2\text{-eq}}$ emissions produced during the product's or activity's lifetime

(Pandey, D. et al., 2011). One of the most common used carbon footprint processes standard is PAS2050, see Figure 2-3 (WPCI, 2010).

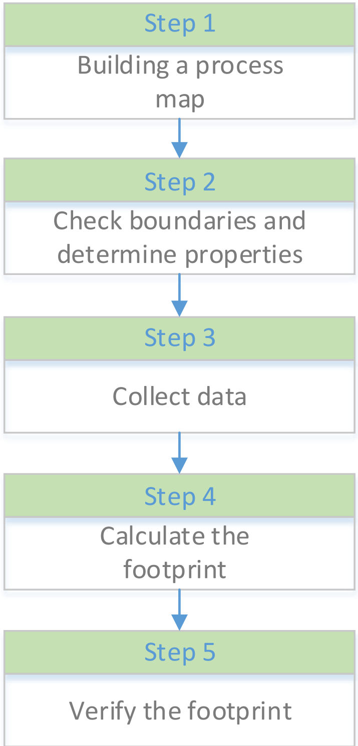

Figure 2-3. The process for a carbon footprint using the PAS2050 standard. Five main steps are in focus; building a process map, check boundaries and determine properties, collect data, calculate the footprint and verify the footprint. The work included in each step is dependent on the objective, credibility, feasibility and cost consideration for a carbon footprint (Inspired by: WPCI, 2010).

The first step in the PAS2050 standard includes building a process map, which comprises the inflow and outflow of materials or energy related to the product or activity. The next step is to check boundaries and determine priorities. It is important to ensure the geographical boundaries and the time horizon as well as make reasonable assumptions. The process therefore depends on the objective for the footprint and characteristics for the product or activity (Pandey, D. et al., 2011). In the third step, data related to the products are collected, including mass or volume for materials or energy used (WPCI, 2010). Data can for example be collected through direct onsite quantities, or based on assumptions for a model related to an activity (Pandey, D. et al., 2011). The choice of collection method depends on the objective, credibility, feasibility and cost considerations related to the carbon footprint.

The next step in the standard is to calculate the footprint (WPCI, 2010). The calculation can involve three different models, which are source data, activity data or emission factors. The source data use details about the emissions source characteristics, which include for example size or power of the engine or power plant, type of fuel consumed or engine technology information. This model is detailed and related to specific used products. The activity data details how the vehicles or equipment operates over time and how the energy use change by mode of operation, such as for example distance and speed. The model that includes emission factors converts the mass or volume of material or energy into $CO_{2\text{-eq}}$ emission rates by using ready-made patterns. Emission factors are the most commonly used model in a carbon footprint (Pandey, D. et al., 2011). The fifth and last step is to verify the footprint and suggest improvement for the calculation (WPCI, 2010). The verification can be done in different ways, such as self-verification, verification by another part or independent third-party verification (Carbon Trust, 2012). The choice of verification method also depends on the objective, credibility, feasibility and cost consideration like the choice of collection method and as the concept for the whole carbon footprint methodology. All steps in the carbon footprint standard provide together a comprehensive estimation of emissions (Melanta, S. et al., 2013). The standard uses a holistic approach by incorporating effects from all phases related to a production of a product or service in an activity.

2.5 Emission factors

To be able to estimate and characterise emissions from different operation sources, emission factors can be used (Pouliot, G., 2012). An emission factor is defined as a factor that converts product or activity data into GHG emissions (GHG Protocol, 2011). The factors are specific for different data, for example materials or fuels and can have different units since it represent the production characteristics (WPCI, 2010). Frequently used units for an emission factor is amount of GHG emissions per used mass, length, volume or equivalent of the product or activity. To calculate the emitted GHG emissions with emission factors, see Equation 2-3,

$$GHG\,emissions = Activity \quad Data \times Emission \quad Factor \times Characterisation \quad Factor \quad [2\text{-}3]$$

where the activity data is the amount of used material, energy or service in a product or an activity. The emission factor corresponds to the emissions related to a product or an activity and is multiplied with the GWP characterisation factor, see Section 2.3, to generate the GHG emissions. All GHG emissions related to the product or activity within the boundaries are normally measured in $CO_{2\text{-}eq}$. Emission factors are quality based which means they change depending on the current conditions, properties and the working environment (Swedish Transport Administration, 2012b). Different emission factors are based on site specific or industry specific data, whereas others include national average data. The emissions can be calculated from technology-based emission factors, from implied emission factors, from an extrapolation of existing data or from a combination, see Table 2-1 (EEA, 2013).

Table 2-1. An emission factor can be used when calculate or quantify air emissions. Two different methodologies for calculating these emissions with emission factors are presented in this figure. The methodologies are either a technology-based approach or an implied approach (Inspired by: EEA, 2013).

METHOD	DESCRIPTION
Technology-based emission factor calculations	Calculation of emissions by combining activity data with an emission factor where both represent detailed emission process conditions and abatement measures.
Implied emission factor calculations	Same principle as above, but both activity data and emission factors represent standard/default conditions taken from guidance documentation.

A technology-based emission factor used in calculations combines activity data with an emission factor. This type of factor uses specific and detailed emissions estimated from the activity processes. The implied emission factor uses instead standard values taken from for example a guidance publication or research study.

There are generally two different types of emission factors for fuels (GHG Protocol, 2011). One type includes combustion of a fuel and the related emissions. The other type relates the emissions to the life cycle of a fuel. Apart from the combustion, this also includes the emissions from raw material extraction, processing, transportation of fuels and the emissions from primary energy. This is the most common phases included in an emission factor for a specific material. Since emission factors often refer to a specific material or fuel, they are therefore already allocated and include different assumptions about site production and fuel consumption. When a factor covers from raw material extraction to user phase for a fuel, it is called “well-to-wheel”. Compared to Life Cycle Assessment (LCA), this is the same expression as “cradle-to-gate” for a product, which is a commonly used expression for materials, and is not covering a possible disposal or recycling step, called “cradle-to-grave” in an LCA.

2.6 Description of ports

Each description of the ports begins with an introduction of their initial environmental work and which method they use for calculating emissions. It follows by examples and implementation of GHG emission reduction actions and continues with emission reduction targets to achieve lower emissions. The general technical aspects include for example reduction of energy use, waste generation and implementation of renewable energy sources. For further reading and more examples about the ports, see references for respectively port.

2.6.1 Port of Antwerp

The Port of Antwerp started their work with sustainability reporting in 2010 and launched the first Sustainability Report in 2012 (Port of Antwerp, 2013). The Sustainability Report is written in accordance with the Global Reporting Initiative guidelines. Before the suitability reporting process, the port implemented a sustainability policy in 2007, which served as a basis for the environmental work. The emissions related to port activities have been monitored for the Port of Antwerp through the Flemish Environment Agency since 1990 and include the substances NO_x, SO_2, and PM.

In recent years, the Antwerp Port Community has invested in combined heat and power (CHP) (Port of Antwerp, 2011). Generally, a CHP installation uses less fuel to generate the same amount of energy in comparison to electricity from the grid and heat from a traditional boiler. A CHP is therefore more efficient and results in primary energy savings. The Port of Antwerp has also invested in renewable energy. In 2004, the first two wind turbines were installed in the north of the port area. The expansion of the wind farm will develop to a maximum of 55 wind turbines the coming years. In 2010, Antwerp Port Authority accepted the policy for solar panels in the port area. The concession holders are permitted to install solar panels with a maximum capacity of 5MW per installation. Today, the Port of Antwerp produces environmentally labelled electricity from several energy sources. Another energy source used is biomass, which will support the port to reduce the current GHG emissions with 20% by 2020.

Callebaut[2] describes that the Port of Antwerp currently undertake the task of reducing energy use in buildings and has set a target by year 2020 to reduce the amount by 10 % compared with today’s level. More generally, the tug boats are the most difficult part under port control

[2] Karen Callebaut, Senior technical manager environment Port of Antwerp, personal communication 13 March 2014.

to reduce emissions from. They contribute to half of the energy consumption from Antwerp Port Authority. It is also difficult to reduce their emissions but one measure is to change the human behaviour. The Port of Antwerp has therefore introduced the concept Eco shipping applied to the tug boats, which is similar to the concept ecodriving. This means restricted use of the engines and also to better plan the routs. The fuel consumption will also be monitored. These actions are assumed to lower the emissions from the boats by 5 % in the near time.

According to Callebaut[1], the Port of Antwerp has not calculated CO_2 emissions related to construction and maintenance operations because of the high data uncertainty. The source of materials and the amount of recycled materials as inputs is difficult to pin down and calculate. The Port of Antwerp has thus taken construction operations into account for SO_2 and NO_x emissions. The emissions related to construction are from the machinery in off roads vehicles used in the port area (Port of Antwerp, 2011). According to Verhoeven[3] the estimated emissions are based on the data collection and emission calculations performed by the Flemish Environment Agency from a model called OFFREM.

2.6.2 Port of Gothenburg

The Port of Gothenburg´s first sustainability report was launched in 2012 (Port of Gothenburg, 2013). The port publishes a report on an annual basis and the emission estimations method used is a carbon footprint assessment. Gothenburg Port Authority has calculated a carbon footprint since 2010 and currently works with expanding the carbon footprint from different indirect emission sources. The calculated sources are for example operational vessels and vehicles (direct emissions), district heating and electricity usage (indirect emissions) and business travels, car pool and vessels at the quay and in the traffic area (indirect), see Appendix II for a more comprehensive description on what is included in the direct and indirect emissions. The carbon footprint is a part of their climate programme, which is based on the ISO 14064 standard.

By 2015, Gothenburg Port Authority has the ambition to become totally climate neutral including operational activities under own control (including scope 1, scope 2 and business and flight travels) (Port of Gothenburg, 2013). This ensures that Gothenburg Port Authority will financially compensate for the possible surplus amount of emissions emitted after that year. By 2016, Gothenburg Port Authority has the target to emit a maximum of 190 000 tonnes $CO_{2\text{-eq}}$ emitted from Gothenburg Port Authority including the indirect emissions measured today. In the coming years, emissions from additional indirect port activities, terminals and operators will be calculated and included in the carbon footprint. Additional targets for Gothenburg Port Authority are to decrease the indirect climate emissions by 5% by 2015 compared to 2010 and also to decrease the climate emissions in scope 1, scope 2 and business fights and travels in scope 3 by 40% by 2015 compared to 2010.

Gothenburg Port Authority has established different actions to reduce GHG emissions. One action is the expansion in rail traffic to and from the port instead of increased transport by trucks or aviation (Gothenburg Port Authority, 2012). In 2000, the Port of Gothenburg was the first in the world to offer onshore power supply with high-voltage for commercial vessels. This means vessels can connect their cables onshore to supply electricity from the Swedish grid. The onshore electricity power also generates a more quiet port surrounding and a better work environment on-board. The electricity that Gothenburg Port Authority uses in activities

[3] Tim Verhoeven, Environmental Assistant Port of Antwerp, personal communication 24 March 2014.

and buildings is environmentally labelled. This gives an almost GHG free usage of electricity, with wind as an example of energy source. Gothenburg Port Authority also works with lowering their waste flows. According to Dörrheide[4], the port uses for example the end of life concrete and crushes it into small pieces and filling areas, such as holes, within the port.

2.6.3 Port of Los Angeles

The Port of Los Angeles launched its first emission inventory in 2004, with the baseline year of 2001 (Port of Los Angeles, 2013) and has since then performed a GHG inventory on an annual basis, covering sources under port control (Los Angeles Harbor Department, 2008). The emission inventory is included in the environmental report is written in accordance with the Global Reporting Initiative guidelines. The emission estimation is based on a GHG emission activity-based method (The Port of Los Angeles, 2011). The port has annually expanded the GHG emissions inventory to cover indirect emissions, i.e. scope 3 emissions. Since 2006, the port has expanded the geographically boundaries to include emissions from ocean-going vessels, heavy-duty vehicles, and rail locomotives (Los Angeles Harbor Department, 2008). The expanded GHG emission inventory also includes indirect GHG emissions associated with tenant operations, harbour craft, and cargo handling equipment. The inventory does not include emissions from construction and maintenance operations.

By 2030, the emission reduction target for Port of Los Angeles is to reduce 1990's GHG emission level by 35 % and by 2050 to reach 80 % below 1990's levels (Port of Los Angeles, 2012). These targets are included in the port's action plan and to achieve this, the port needs to take actions. The port are for example increasing the generation of renewable energy, improving energy conservation and efficiency and changing transportation and land use patterns to reduce dependence on automobiles, among others. The port purchases 25 % of the power from renewable energy sources. Other operations are the installation of 1MW of solar panels on the roof of one terminal and certification of buildings through Green Building Policy and LEED Certification. The port has also increased the recycling capacity. As a last example, the port has implemented green technology pilot projects for electric and hybrid trucks used in the port area, electrified tugboats, and cargo-handling equipment.

Los Angeles Harbor Department has established guidelines to improve the port's environmental work in development and construction within the port area, called the Sustainable Construction Guidelines, see Appendix III, the Sustainable Engineering Design Guidelines, see Appendix IV, and the Green Leasing Policy (Los Angeles Harbor Department, 2008). The ISO certification for the Environmental Management System for construction increases safety, reduces spills, and increases recycling. Emission estimation related to the buildings is not included. The Port Green Building Policy requires all new port buildings of 700 m^2[5] or more to meet a minimum standard and be evaluated with the LEED Existing Building rating system. The policy also requires all new port buildings to install solar power to the maximum possible extent, as well as incorporate the best available technology for energy and water efficiency. The port requires all container terminal operators to monitor energy use in terminal buildings to identify savings measures.

[4] Elin Dörrheide, Project Manager Gothenburg Port Authority, personal communication 26 March 2014.

[5] Recalculated from 7,500 square feet

2.6.4 Port of Valencia

In 1998, Valencia Port Authority started the Ecoport project, aiming to work towards an environmentally protecting port community (Port of Valencia, 2012). This project implemented and developed a methodology for the implementation of Environmental Management Systems in port environments. On an annually basis, the Port of Valencia has performed a carbon footprint according to the PAS2050 standard. The carbon footprint covers indirect emissions such as electricity consumption and business travel but no other indirect sources. In 2011, the Port of Valencia implemented an action plan on how to reduce emissions. It includes reduction of energy use in transport infrastructure and port installations, promotion of research and development of energy efficiency in ports. It also includes energy use monitoring and control in ports, electric energy supply to ships and vessels on shore and installation of solar PV panels on public buildings in the port. According to Jiménez[6], Valencia Port Authority has the ambition to develop a software tool to compute and evaluate trends of carbon footprint and GHG emissions applied to the port.

In 2010, Valencia Port Authority carried out a study towards energy efficiency in buildings to determine consumption levels and identify the principal consumption sources (Port of Valencia, 2012). One measure was to reform the pumping system in the refrigeration plant. Another related study checked the implementation of environmental certifications of port buildings to improve the energy performance. Other actions taken are to measure water and electricity consumption and substitute vehicles with other models that generate lower emissions. The Port of Valencia control and determine fuel consumption per employee and machine (Climeport, 2010). When it comes to the electrical consumption, the flow is reduced night time due to the working hours day time.

The most relevant indicators used for Port of Valencia are electricity consumption, water consumption, fuel consumption, biodiversity, paper, hazardous goods, non-hazardous goods and direct and indirect $CO_{2\text{-eq}}$ emissions (Port of Valencia, 2012). The indicators follow the Global Reporting Initiative methodology and are Environmental Management System III certified. The environmental work in Port of Valencia has resulted in different recommended improvements. It is for example important to reduce the waste generated at source when possible or alternatively reuse the waste. Further, separate hazardous waste into different categories to make the treatment easier. Other examples are to reduce the fuel consumption and emissions and monitor and inspect the vehicles on a regular basis. When possible, use drip irrigation for watering plants and reuse water. There are other aspects not included, such as construction and maintenance activities in ports and infrastructure. According to Jiménez[3], one reason for this is that Valencia Port Authority is only considering the emissions from the port commercial activities.

According to Torres[7], Port of Valencia work with near term emission reduction targets depending on the climate action in place, in order to fulfil the Environmental Management System. To select which climate actions to work with, the port works in parallel with different projects. For example carbon footprint, energetic efficiency and GHG emission reduction, to get the knowledge to be able to introduce climate actions in the Environmental Management System and create specific emission reduction targets for each action.

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[6] Raúl Cascajo Jiménez, Head of Environmental Policies Port of Valencia, email conversation 19 February 2014

[7] Federico Torres Monfort, Director of General Services, personal communication 9 May 2014

3. Method

The method chapter begins with the methodology for mapping ports and later includes the data collection and the emission calculations from construction and maintenance in the port. The mapping is performed as a literature study based on the description of ports in previous chapter and by personal communication with each port. The emission inventory is a data collection measured in mass or volume of materials and energy related products used in selected constructions and maintenance projects during 2013, collected from invoices. The emission inventory is dependent on the collection of emission factors applied for each material or energy related product used. Finally, the method for the development of guidelines is described.

3.1 Method for mapping ports

The mapping of ports will give a broad description on how the different ports incorporate environmental protection and emission calculations. It is preferable if a number of ports can be selected in order to be able to give several examples and highlight alterations as well as similarities. The different ports should be located in different areas and incorporate climate actions and $CO_{2\text{-eq}}$ emissions estimations. Together with Susann Dutt, Quality Manager & Sustainability Specialist at Gothenburg Port Authority, three ports except Port of Gothenburg is selected for mapping. These three are some of the world's leading ports in environmental work; Port of Antwerp, Port of Los Angeles and Port of Valencia.

The description of each port is performed by contacting the ports, to receive documentation of their current and future work towards emission reduction actions and emission reduction targets. The documentation is based both on environmental reports and personal communication with environmental specialist at the different ports. The results from the description of ports are presented as the mapping based on three selected key factors that give an overview of the environmental work. The key factors are set to:

- The port's early work with environmental impacts and emission calculations
- Examples of emission reduction actions
- Emission reduction targets

To make the result clear and easy to follow, only main findings from the description of ports in Section 2.6 are presented for each of the three key factors. The factor "the port's early work with environmental impacts and emission calculations" includes the year when the first environmental report was launched and comments about emission methodology chosen to present the emissions. In the next factor, "examples of emission reduction targets", all ports have many emission reduction actions and only some examples are presented in a list. In most cases, several ports can be related to an action and the actions are therefore not linked to a specific port in the list. All selected actions aim for emission reductions achievements. The reason for choosing to present the actions in a list, independent of which port it originally came from, is because the main point is to present various alternatives and offering possibilities of exchange experiences. For further information about emission reduction actions taken from the ports, see Section 2.6 and the references related to each port. The last key factor is chosen to be emission reduction targets, which present different targets, both near terms and long terms, for reducing GHG emissions, other emissions or energy used from the four different ports.

The amount of emissions are difficult to compare between the ports since they use different system boundaries, they have different geographical locations and assist dissimilar transport vehicles. Therefore, no numbers of emissions are compared but instead the expected targets in percentages for some ports. The result from the mapping serves as a basis for the development of guidelines. There are however other parameters that regulate the environmental work at the different ports (Climeport, 2010). Ports have for example different legal framework, which can support or oppose the implementation of environmental work.

3.2 Data collection of used materials and energy related products

Conducting a $CO_{2\text{-eq}}$ emission inventory is only one part in a broader environmental management initiative (Franchetti, M.J. & Apul, D., 2012). This study develops the carbon footprint for Gothenburg Port Authority and is included in steps one to five in the iterative process circle for development of a climate program, see Figure 3-1. In this thesis, the remaining steps are implementation and follow up the work of the initiative. These steps are included in the guidelines and discussion about emission calculations for construction and maintenance projects for at the Port of Gothenburg. To establish a yearly calculation from construction and maintenance operations, all iterative steps are preferably included in the initiative.

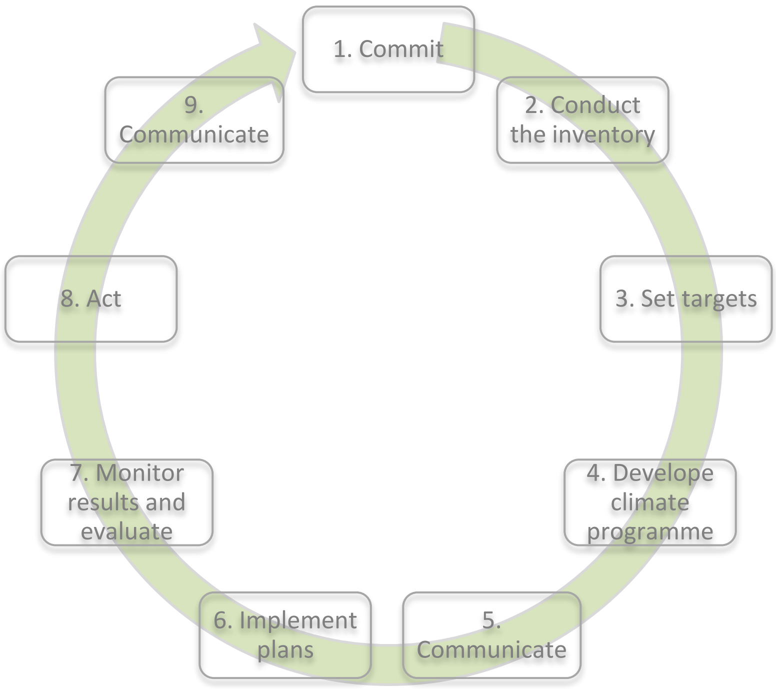

Figure 3-1. The nine iterative steps for development of a climate programme, which is similar to conduct a carbon footprint assessment. The steps are commit, conduct the inventory, set targets, develop climate programme, communicate, implement plans, monitor results and evaluate, act and once again communicate before the cycle could be repeated (Inspired by: Franchetti, M.J. & Apul, D. 2012).

During 2013, approximately 160 infrastructure related projects in total were conducted at Gothenburg Port Authority. Since the amount of projects needed to be scaled down, a boundary for which projects to investigate are established. The selection of investigated projects was based on the related investment cost, which generally are linked to the amount of materials used. It is also presupposed to cover a broad type of repeated projects included in the infrastructure development. The aim with the result is to easily determine trends over time. The type of construction and maintenance projects chosen are called reinvestment projects since they have a high cost and are involving a variation of suppliers and materials. During 2013, 22 reinvestment projects were conducted and included for example quay maintenance, replacement of pipelines and ice protection forms, which are protecting the poles in the quay construction. The results from the construction and maintenance projects will be indicative for the further environmental work and the method could be implemented in all future projects related to construction and maintenance.

The used materials and energy related products for construction and maintenance operations are collected from invoices during 2013. The categories include common article of consumptions such as construction materials or energy related products used, see Table 3-1. The energy related products category is including fuels, electricity and when these two are used in a vehicle or equipment. The materials are sorted into asphalt, cement, composite materials, concrete, plastics, wood related products and others. In the category "others", the materials that contribute to the least amount of $CO_{2\text{-eq}}$ emissions are summarised. The different materials and energy used in the selected projects are sorted and measured in mass or volume. The material and energy related products are further sorted into different types. If possible, the collected mass or volume is based on the product information from each supplier. In other cases, only the product is stated and the mass of the materials has to be assumed based on density. For a more comprehensive view of the different materials and energy related products used, see Appendix V.

Table 3-1. Different types of general categories from the collected materials or energy related products from invoices for construction and maintenance operations performed at the Port of Gothenburg. Each category contains different subcategories of materials. The materials have different properties but these are presented under the main category. "Others" include the materials that contribute the least to $CO_{2\text{-eq}}$ emissions.

MATERIALS	ENERGY RELATED PRODUCTS
Asphalt	Diesel
Cement	Gasoline
Composite materials	Electricity[a]
Concrete	Use of vehicles - fuels
Plastics	Use of equipment - fuels
Wood related products	
Others	

a. Electricity is already included in the current scope 2 for the majority of the port operations but included in the inventory where the operators have assigned specific electricity use.

There are some materials and energy related products that are not included in the inventory. The rented equipment serves also other projects at other companies apart from the Port of Gothenburg and is excluded due to the difficulty related to emission allocation. Other products of more complex structure, such as batteries, fans and other electrical equipment are also excluded because of the high uncertainty of relevant emission data. These also have another lifetime than the construction itself or are in other cases used in several projects. The rate of recycled content in different material or products is assumed in the emission factors, which include standard average values.

3.3 Data collection of emission factors

The carbon footprint calculation can involve source data, activity data or emission factors. This thesis uses the emission factors, which need to be collected for used materials and energy related products, see Appendix V. This thesis uses implied emission factor, which means standard values from other studies or publications, see Table 2-1. The emission factors for material and energy use are not site specific, but specific for Europe and Sweden. The emissions from the material include general emissions from raw material extraction, production and distribution of fuels to generate energy. The collected mass and volumes are quality assured and represent the used material or energy related products within the port operations. The more uncommon materials without any emission factors use factors from similar products. Developing new emission factors or conduct a new LCA for materials, were decided to lie beyond the scope of this thesis.

In the result chapter, see Section 4.2, $CO_{2\text{-eq}}$ emissions from a product are summarised into the main categories of materials or energy related products. As an example, the group “concrete” contains different types of concrete with different properties. It includes for example frost free concrete, suitable for the port environment, and also concrete used under the water surface. In this thesis, all types of concrete uses the same average emission factor applied to concrete. The group “plastics” include polypropylene, polyethylene, polystyrene and polyvinyl chloride (PVC). The different types of plastics have their own emission factor applied. The group “steel” includes reinforcement steel, stainless steel, carbon steel and galvanized steel among others. Almost all different types of steel have their own emission factor applied. The group “diesel and gasoline” includes all types of fossil fuels used. The types of fuels uses average emission factor, in terms of for example fuel mix, applied to each fuel. All emission factors used are presented in the next two sections and Appendix V.

3.3.1 Emission factors for different materials

The emission factors for different materials are mainly collected from the Swedish Transport Administration (2014a), UK environmental agency (2012) and IPCC (2006). All emission factors are verified and qualified by comparing at least two source references, except for the references from personal communication. The most likely emission factors applied for Swedish conditions are chosen. The different materials found in the inventory process are grouped into the 22 material types presented in Table 3-2 together with their corresponding emission factors.

Table 3-2. The emission factors for commonly used materials in the selected port construction and maintenance projects at the Port of Gothenburg.

Material	Emission factor	
Acidproof stainless steel	4.5	kg $CO_{2\text{-eq}}$ /kg[8]
Aluminium	8.4	kg $CO_{2\text{-eq}}$/kg[8]
Asphalt	0.051	kg $CO_{2\text{-eq}}$ /kg[8]
Carbon steel	1.5	kg $CO_{2\text{-eq}}$ /kg[8]

[8] Ref: Swedish Transport Administration, 2014b

Cement	0.715	kg $CO_{2\text{-eq}}$ /kg[8]
Composite material	57	kg $CO_{2\text{-eq}}$ /kg[9]
Concrete	0.153	kg $CO_{2\text{-eq}}$ /kg[8]
Glass reinforced plastic	8.1	kg $CO_{2\text{-eq}}$ /kg[9]
Galvanised iron	2.03	kg $CO_{2\text{-eq}}$ /kg[9]
Galvanised stainless steel	1.87	kg $CO_{2\text{-eq}}$ /kg[8]
Iron	2.03	kg $CO_{2\text{-eq}}$ /kg[9]
Rubber	2.85	kg $CO_{2\text{-eq}}$ /kg[8]
Paper	0.52	kg $CO_{2\text{-eq}}$ /kg[8]
Plywood	584	kg $CO_{2\text{-eq}}$ /m^3 [8]
Polyester	2.7	kg $CO_{2\text{-eq}}$ /kg[8]
Polyethylene	2.5	kg $CO_{2\text{-eq}}$ /kg[9]
Polypropylene	1.98	kg $CO_{2\text{-eq}}$ /kg[8]
Polystyrene	3.38	kg $CO_{2\text{-eq}}$ /kg[8]
PVC plastics	3	kg $CO_{2\text{-eq}}$ /kg[8]
Reinforcement steel	0.72	kg $CO_{2\text{-eq}}$ /kg[8]
Stainless steel	6.5	kg $CO_{2\text{-eq}}$ /kg[8]
Zink	1.72	kg $CO_{2\text{-eq}}$ /kg[10]

3.3.2 Emission factors for energy related products

The collected mass and volume data need to be converted to the same unit as the emission factor. For the emission factors that have another unit than the collected mass or volume data from the invoices, see Appendix V. Assumptions are made for vehicles with the emission factor unit in km since only hours in use are specified in the invoices for some vehicles. It is difficult to measure the amount of travelled distance in km but when comparing invoices, which stated travelled distances during a day, the average value for a vehicle, such as a pick-up or a truck could be related to drive approximately 30 km per hour. There are however periods of idling driving, which is assumed to be included in the average speed chosen. If the amount of diesel consumed per hour is known instead, the emission factor for diesel is used in the $CO_{2\text{-eq}}$ calculation. The heavy and light trucks use emission factors applied to urban traffic.

The emission factors for different energy related products are mainly collected from the Swedish Transport Administration (2014a; 2012b), Trafikkontoret (2012), IVL (Erlandsson, M., 2014) and Preem (2014), but also from personal references. The energy related products found in the inventory process are grouped into the 15 categories presented in Table 3-3 together with their corresponding emission factors. In the result chapter, the emissions from all energy related products are either presented as emission from diesel and gasoline or as electricity depending on the energy source in each vehicles or equipment.

[9] Ref: UK Environmental Agency, 2012
[10] Ref: IPCC, 2006

Table 3-3. The emission factors for commonly used vehicles, equipment and fuels in the selected port construction and maintenance projects at the Port of Gothenburg.

Energy related products	Emission factors	
ACP Evolution Diesel	2.72	kg $CO_{2\text{-eq}}$ /l[11]
Alkylate gasoline	2.13	kg $CO_{2\text{-eq}}$ /l[12]
Biodiesel 100, RME 100%	1.5	kg $CO_{2\text{-eq}}$ /l[11]
Bulldozer	48.1	kg $CO_{2\text{-eq}}$ /h[8]
Compressor	107.3	kg $CO_{2\text{-eq}}$ /h[13]
Concrete pump	0.9	kg $CO_{2\text{-eq}}$ /m^3[14]
Crane	59.5	kg $CO_{2\text{-eq}}$ /h[8]
Diesel	2.98	kg $CO_{2\text{-eq}}$ /l[15]
Electricity, Swedish average mix	0.02	kg $CO_{2\text{-eq}}$ /kWh[8]
Excavating machine	26.9	kg $CO_{2\text{-eq}}$ /h[8]
Gasoline 95	2.67	kg $CO_{2\text{-eq}}$ /l[15]
Heavy truck	0.80	kg $CO_{2\text{-eq}}$ /km[16]
Jet cutting (diesel)	119.2	kg $CO_{2\text{-eq}}$ /h[14]
Jet cutting (electricity)	0.2	kg $CO_{2\text{-eq}}$ /h[14]
Light truck/Pickup	0.24	kg $CO_{2\text{-eq}}$ /km[16]

3.3 Method for calculating $CO_{2\text{-eq}}$ emissions

The type of projects within the construction and maintenance area all involve different processes such as site-preparation, operation of equipment, landscaping, production and use of materials, e.g. asphalt, concrete, and metals among others (Melanta, S. et al., 2013). The result is presented as a carbon footprint and to calculate the carbon footprint, emissions factors are used. A description of the calculation for emissions in construction and maintenance projects are presented in Figure 3-2. Performing a carbon footprint on infrastructure projects is complex and needs a lot of assumptions (Swedish Transport Administation, 2012a).

[11] Ref: Preem, 2014
[12] Ref: Personal communication: Preem
[13] Ref: Erlandsson, M., 2014
[14] Ref: Personal communication: contractors
[15] Ref: Trafikkontoret, 2012
[16] Ref: Swedish Transport Administration, 2012b

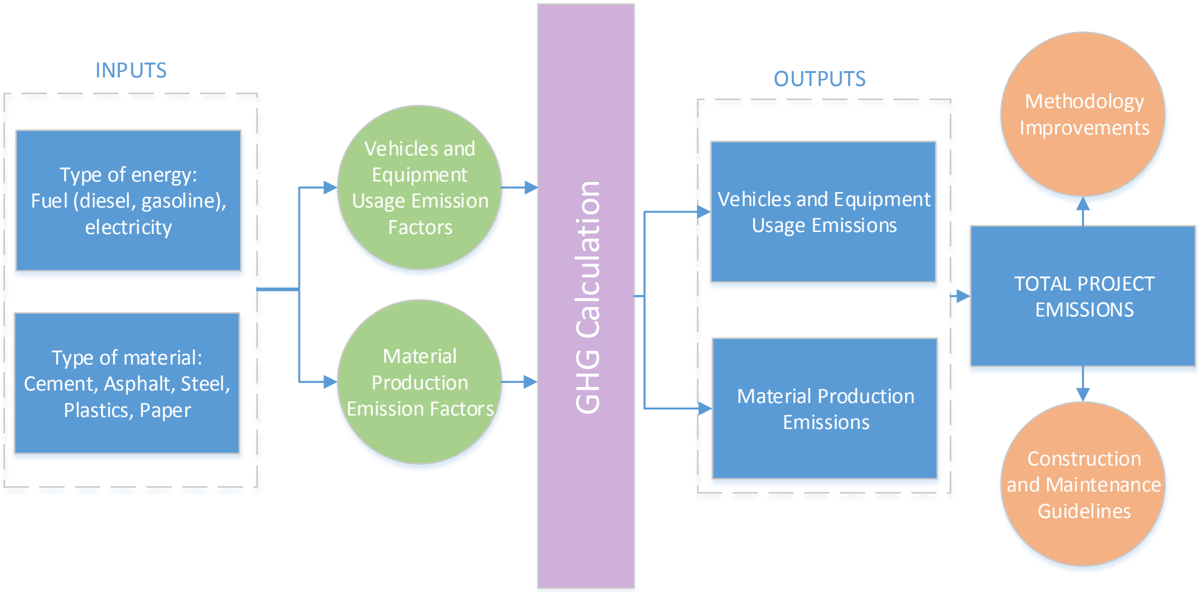

Figure 3-2. A description of the pathway for conducting a carbon footprint for construction or maintenance projects. The inputs are collected and calculated with emission factors, converting the usage into GHG emissions measured in $CO_{2\text{-eq}}$ as output. The total emissions serve as a base in the development of guidelines on how to work with emission reduction related to the materials and energy usage generating high levels of emissions in the outputs and also to be able to evaluate the result and find methodology improvements (Inspired by: Melanta, S. et al., 2013)

The input data, which is the mass and volumes used in the construction and maintenance projects, is collected as described in previous section. The materials and energy used in the construction and maintenance projects are summarized and grouped into several product types. The emissions factors are used as in Equation 3, together with the mass and volumes collected for materials and energy related products from the 22 selected construction and maintenance projects during 2013. The emission factors are multiplied with each category given that the right units are used; otherwise these are converted, to complete the GHG calculation step. Since the emission factors include data from parts of the life cycle for the materials or energy related products, the results from the calculations will also be based on a life cycle perspective. The outputs are emissions related to the activities. These are in turn summarised into the total emissions for each project and added together as total emissions for the 22 construction and maintenance projects at the Port of Gothenburg. This is the result, i.e. the carbon footprint. Based on the total emissions, suggestions for methodology improvements will be made and general guidelines for construction and maintenance designed, see the methodology in Section 3.4 and the result for the guidelines in Section 4.4.

Emission calculations contain assumptions and the variation of the result can be expressed with an uncertainty factor. The factor is measured in percentages and means that the result can vary from a lower to higher range compared to the calculated result. In this study the uncertainty factor is assumed to be 25 % for all emission factors independent on the source. The carbon footprint calculated from the emission factors from UK Environmental Agency (2012) is expected to be within 25 % of the actual value. The emission factors from IVL are expected to have 20 % uncertainty (Erlandsson, M., 2014). When it comes to the emission factors from Swedish Transport Administration (2014a), IPCC (2006), Preem (2014) and personal references, the uncertainty factor is not measured.

For the emission factors collected from the Swedish Transport Administration (2014a), the emissions are based on average usage of the vehicles and equipment and assumptions about their standards. The emission factors collected for the transport vehicles and other fuel consuming equipment are based on the report from IVL and include an utility factor (Erlandsson, M., 2014). An utility factor means the amount of hour specified in the invoice recalculated to the actually hours when the vehicles or equipment are in use. The utility factor has an uncertainty of 20 %.

The result is presented as a total carbon footprint for the 22 construction and maintenance projects at the Port of Gothenburg. This carbon footprint is compared to the current calculated carbon footprint for Gothenburg Port Authority, which includes several activities in all three scopes, see Appendix II. Since this thesis only investigate 22 projects out of total 160 infrastructure related projects, a rough approximation of what the truly carbon footprint can be including all 160 projects is calculated. The calculation is based on the cost for the remaining projects, which corresponds to 70 % of the total investment in construction and maintenance operations during 2013. The $CO_{2\text{-eq}}$ emissions related to all 160 projects are calculated as in Equation 3-1, including the uncertainty factor of 25 %.

$$Total\ CO_{2-eq} Emissions\ = \frac{CO_{2-eq}\ Emissions}{0.3} \cdot 1.25 \qquad [3\text{-}1]$$

3.4 Method for development of Guidelines

The mapping of ports allows transparency and evaluation between all included ports in terms of $CO_{2\text{-eq}}$ emission calculations and emission reduction actions taken. To be able to reduce emissions from construction and maintenance operations, guidelines on how to achieve the same service but with lower emissions are developed and suggested. This will lead to an overview and a better understanding if ports consider adopting other ports' emission reduction actions (Climeport, 2010). It can also contribute to the implementation of the method on how to calculate a carbon footprint on an annual basis for construction and maintenance projects. Estimate emissions by following the guidelines will increase the capability of Gothenburg Port Authority's work towards more conscious decisions and contribute to their total $CO_{2\text{-eq}}$ emission targets. Other aspects included will be efficiency and behaviour changes.

The guidelines are presented as a list of actions that can be taken both at the construction and maintenance site as well as in the purchase and planning of the operations. The findings from the literature review provide insight that could be used when developing the required management framework. This could also be used when mapping the ports together with detailed information on management practices for environmental impacts and emissions. The guidelines are based on the conclusions from this report, expertise from Gothenburg Port Authority and the other ports including in the mapping. It is also inspired by two documents, "Los Angeles Harbor Department Sustainable Construction Guidelines for Reducing Air Emissions" (Los Angeles Harbor Department, 2009) and "UK Environmental Agency's carbon reduction tips" (UK Environmental Agency, 2012).

4. Results

In this chapter, the results applied to the four objectives of this thesis are presented. The first is the mapping of the ports where the findings from the description of each port are presented in tables. The tables include examples with complementary comments. Secondly, the data collection for mass of materials and volumes of energy related products from the 22 construction and maintenance projects at the Port of Gothenburg are summarised. Figures and tables illustrate the possible allocation of $CO_{2\text{-eq}}$ emission to materials and energy related products used in the activities. Later, the carbon footprint is presented as the result for the $CO_{2\text{-eq}}$ emission calculations for all construction and maintenance projects at the Port of Gothenburg during 2013. Finally, the guidelines for Gothenburg Port Authority's further work towards lower $CO_{2\text{-eq}}$ emissions are presented partial based on the results from the mapping and the carbon footprint assessment.

4.1 Mapping ports

The results from the mapping of the four ports are based on the description of ports in Section 2.6, and presented in Tables 4-1 to 4-3 below. The mapping includes examples of the early work with environmental impacts and emission calculations, which emission reduction actions that have been taken and the planed emission reduction targets.

4.1.1 Ports' early work with environmental impacts and emission calculations

The result for the early work includes the work with environmental impacts and emission calculations, e.g. when the port's first environmental report was launched and comments about emission methodology chosen to present the emissions, see Table 4-1. The emissions measured and/or calculated are not only GHG emissions. The relationship between the year when the port's first environmental report is launched, when the ports started their environmental work and when actions are taken or amount of investments in environmental protection measures, is not measured. All four ports currently work with reporting emissions from their activities. The environmentally or sustainability reports are generally equal in content and setup. The Port of Antwerp, Port of Los Angeles and Port of Valencia follow the GRI guidelines in their reports, whereas the Port of Gothenburg does not.

Table 4-1. The initial work with environmental issues and emission calculations. For each port, the year when the first environmental related report was launched and comments about their reports and if they uses specific methodologies for emission calculations.

Ports' early work with environmental impacts and emission calculations		
Port	**Year – first launched environmental report**	**Comments**
Antwerp	2012	Global Reporting Initiative
Gothenburg	2012	Using carbon footprint
Los Angeles	2004	Using emission inventories Global Reporting Initiative
Valencia	2011	Using carbon footprint Global Reporting Initiative

4.1.2 Emission reduction actions

All four ports work continuously and frequently with emission reduction actions and all have their own action plan. Examples of actions are presented in Table 4-2. The list includes examples of different emission reduction actions that some or all ports work with. Some ports have accomplished or developed similar actions as the others. To get an overview and varied result including different actions, only some actions are presented in the table below. As a common action, all ports have put an effort in reducing energy use. High on the agenda are renewable fuels and also to monitor the current energy flows. Some more examples of emission reduction actions can be seen in Section 2.6 and also in each port's environmental or sustainability report.

Table 4-2. Examples of emission reduction actions that the ports have either implemented or are working with. Some ports have accomplished or developed the similar actions as the others. The comments are for examples where the action takes place or how it is applied.

Action	Example
• Ecodriving	Applies both on-road vehicles and boats
• Combined heat and power	
• Windmills	
• Rail shuttles	Instead of extensive amount of trucks
• Onshore power supply	For incoming vessels
• Environmentally labelled electricity	Not possible in all countries
• Solar panels	For example on terminal roofs
• Environmental certification of buildings	LEED certification
• Electric and hybrid vehicles and equipment	As example dredging vessels
• Cross port organisations with emphasis on emission reduction actions	As for example the EcoPort project
• Reduce or reuse waste	Increase the amount of recycled products
• Carbon footprint software tool	To calculate $CO_{2\text{-eq}}$ emissions applied to port activities

4.1.3 Emission reduction targets

Each port has different opportunities to lower their emissions but all have set up emission reduction targets to reach lower emissions. In Table 4-3, the future plans for the ports' emission reduction are presented. As an example, Los Angeles Harbor Department has set up targets to meet in approximately 35 years from now, whereas Gothenburg Port Authority works towards an emission reduction target realised in 2015. Valencia Port Authority evaluates instead which climate actions to prioritise and work with every year. Valencia Port Authority's emission reductions follow from the different actions taken, but the port does not set up general numbers as targets.

Table 4-3. The emission reduction targets for each port. Main targets are presented on when and to what exteent the emissions can be expected to be reduced. Also including comments which describes the emission reduction target or give examples on actions how to achieve the targets.

Emission reduction targets		
Port	**Target**	**Comments**
Antwerp	20 % GHG reduction by 2020 compared with 2010 10 % energy reduction from buildings by 2020 compared with today's levels 5 % emission reduction from tug boats	Renewable energy Monitoring energy use Ecodriving
Gothenburg	No net CO_2 emissions, consider the Port Authority by 2015 Conserve the carbon footprint of today´s level to 2016 Decrease the indirect GHG emissions by 5% by 2015 compared to 2010 Decrease the GHG emissions in scope 1, scope 2 and business fights and travels in scope 3 by 40% by 2015 compared to 2010	Financial compensate for the surplus of CO_2 emissions. Improving energy efficiency, using environmentally labelled electricity, increasing the rail service, using on-shore power supply for commercial vessels.
Los Angeles	35 % GHG reduction by 2030 compared to 1990 80 % GHG reduction by 2050 compared to 1990	Renewable energy, improving energy conservation and efficiency, changing transportation and land use patterns to reduce dependence on automobiles, green certification of buildings.
Valencia	Several reduction targets related to climate actions	Different climate actions from year to year, which generate emission reductions. No specific reduction values.

4.2 Mass of used materials

There are several materials used in construction and maintenance projects. The most common materials are collected in this report and converted into related $CO_{2\text{-eq}}$ emissions. A list of all materials comprised, the different variants, and the mass or volume used are included in

Appendix V. The results are presented both in terms of used materials and generated emissions related to different materials and energy related products used.

The mass of the materials used in the 22 construction and maintenance projects are approximately 1060 tonnes, see Table 4-4. Since the fuel and electricity are included in several equipment and vehicles and sometimes unknown, their mass is excluded.

Table 4-4. The materials included in the 22 construction and maintenance projects at the Port of Gothenburg during 2013 and the different fractions used, both in amount measured in mass and in percentage of the total sum. In total, 1054 tonnes of materials were used.

MATERIAL	MASS	UNIT	PERCETAGE	
Asphalt	79	tonnes	7.5	%
Cement	6	tonnes	0.6	%
Composite material	0.3	tonnes	0.0	%
Concrete	873	tonnes	82.3	%
Plastics	2	tonnes	0.2	%
Wood related products	33	tonnes	3.1	%
Steel	61	tonnes	5.7	%
Others	6	tonnes	0.6	%
SUM	**1060**	**tonnes**	**100**	**%**

Concrete alone serves as the most consumed material based on total mass, with around 870 tonnes. The asphalt is the second largest, with nearly 80 tonnes and the steel third with approximately 60 tonnes. The distribution among the materials is presented in Figure 4-1.

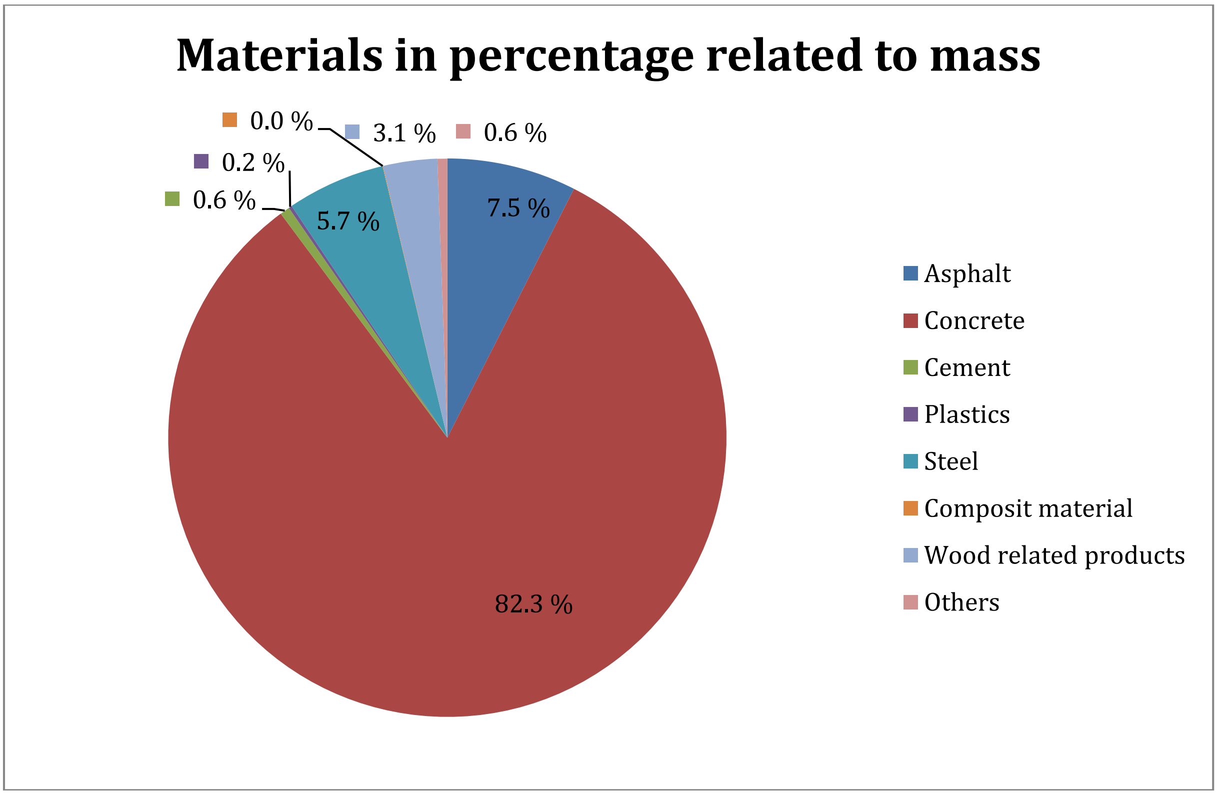

Figure 4-1. The distribution related to the mass in percentages for the used materials in the 22 construction and maintenance projects at the Port of Gothenburg during 2013.

4.3 CO_{2-eq} calculations – The carbon footprint assessment

Only some of the used materials stand for the majority of the CO_{2-eq} emissions, which are fossil fuels (diesel and gasoline), steel and concrete, see Table 4-5. The total carbon footprint for the 22 construction and maintenance projects during 2013 is about 1340 tonnes CO_{2-eq}. The materials below 0.2 % of the total CO_{2-eq} emissions is summarised as "others" and are for example different metals, paper, rubber and electricity.

Table 4-5. The materials included in the 22 construction and maintenance projects at the Port of Gothenburg during 2013 and the generated CO_{2-eq} emission. In total, 1336 tonnes of CO_{2-eq} were emitted from these operations.

MATERIAL	CO_{2-eq} EMISSIONS	UNIT	PERCETAGE	
Asphalt	4.0	tonnes	0.3	%
Cement	4.1	tonnes	0.3	%
Composite material	13.2	tonnes	1.0	%
Concrete	133.6	tonnes	10.0	%
Diesel and gasoline	896.3	tonnes	67.1	%
Plastics	6.4	tonnes	0.4	%
Wood related products	7.8	tonnes	0.6	%
Steel	252.4	tonnes	19.0	%
Others	18.2	tonnes	1.3	%
SUM	**1336**	**tonnes**	**100**	**%**

The results in Table 4-5 are also presented as an overview in Figure 4-2. In Figure 4-2 the materials contribution to CO_{2-eq} emissions in percentages for the 22 construction and maintenance projects.

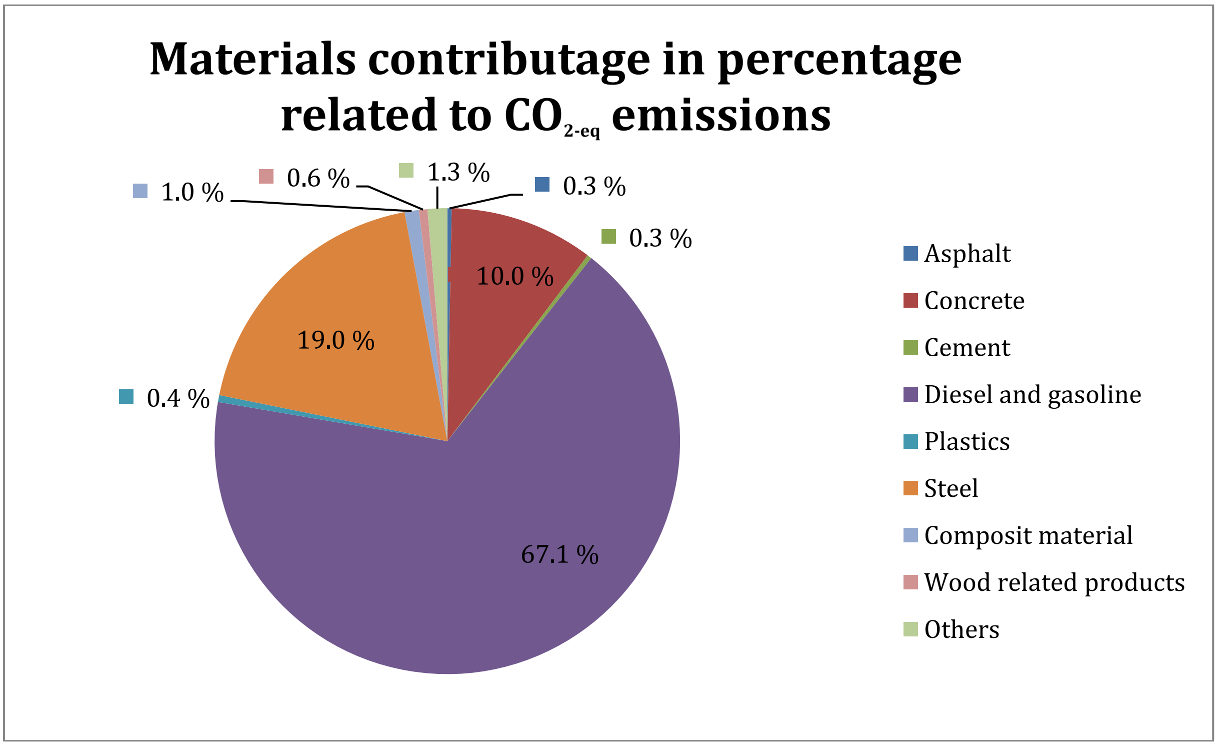

Figure 4-2. The different main materials and fuels, used in the 22 construction and maintenance projects at the Port of Gothenburg during 2013, and their contribution to the total $CO_{2\text{-eq}}$ emissions.

As seen in Figure 4-2, some materials and energy related products have a larger contribution to the level of $CO_{2\text{-eq}}$ emissions. Diesel and gasoline generate the highest $CO_{2\text{-eq}}$ emissions from the 22 construction and maintenance projects during 2013. Diesel and gasoline together generate around two thirds of the $CO_{2\text{-eq}}$ emissions. Also the materials concrete and steel generate high levels of $CO_{2\text{-eq}}$ emissions from construction and maintenance during 2013.

It is the production of steel that generates high levels of $CO_{2\text{-eq}}$ emissions. Steel with special properties, such as stainless, acid-proof or galvanized steel, have a more complex and energy demanding production. Untreated steel has generally low emission factors. Steel with special properties can therefore have an emission factor nine times higher than untreated steel, see Appendix V. When all steel types are summarised together, they correspond to around 19 % of the total $CO_{2\text{-eq}}$ emissions.

Concrete is another material with high levels of $CO_{2\text{-eq}}$ emissions, generating around 10 %. One reason why concrete emits high levels of $CO_{2\text{-eq}}$ is because of its composition. Concrete is a mixture of inert mineral aggregates such as sand, gravel, crushed stones, and cement (Worrel, E. 2004). It is thus important to know that emissions related to concrete can be allocated differently. Concrete and cement for example, need a lot of supporting equipment and vehicles, which generate emissions. It can include transportation and also the equipment used for concrete related activities such as jet cutting and concrete pumps which stand for the majority part of the diesel and electricity consumption. Two third of the amount of diesel and electricity can be related to concrete, and is in this case the material related to most $CO_{2\text{-eq}}$ emissions, approximately 60 %.

The result of 1340 tonnes $CO_{2\text{-eq}}$ emissions can be compared with the emissions calculated for Gothenburg Port Authority in 2013. Gothenburg Port Authority included several activities generating $CO_{2\text{-eq}}$ in scope 1 and scope 2 and scope 3 (called Current scope 3), see Table 4-6 and also Appendix II.

Table 4-6. The current estimation of the carbon footprint in scope 1, scope 2 and scope 3 for Gothenburg Port Authority. Also the calculated carbon footprint from the 22 construction and maintenance projects at the Port of Gothenburg during 2013. The total updated carbon footprint reaches 192 120 tonnes $CO_{2\text{-eq}}$.

Carbon footprint – Gothenburg Port Authority	
Scope 1	460 tonnes $CO_{2\text{-eq}}$
Scope 2	330 tonnes $CO_{2\text{-eq}}$
Current Scope 3	190 000 tonnes $CO_{2\text{-eq}}$
Total (current)	**190 790 tonnes $CO_{2\text{-eq}}$**
Maintenance and construction operations[17]	1 340 tonnes $CO_{2\text{-eq}}$
Total (updated)	**192 130 tonnes $CO_{2\text{-eq}}$**

The emissions in scope 1 and scope 2 for the whole Gothenburg Port Authority are divided into direct related emissions, and indirect from electricity and district heating. These emissions can be compared to the emissions from the 22 construction and maintenance projects during 2013 generate more than twice as much emissions, see Figure 4-3.

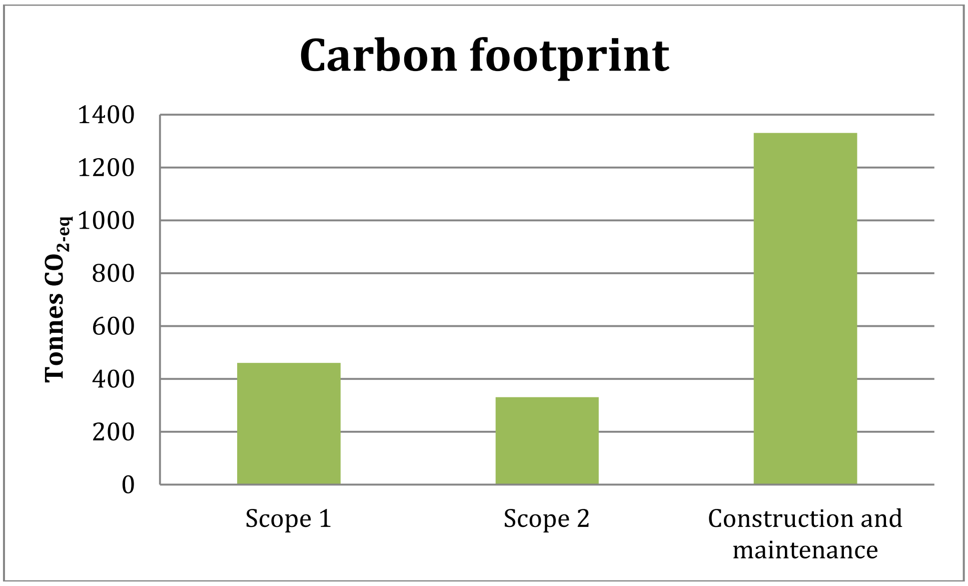

Figure 4-3. The result from the 22 construction and maintenance projects at the Port of Gothenburg during 2013, called here only "construction and maintenance". This is presented together with scope 1 and scope 2 for Gothenburg Port Authority from 2013. Scope 1 includes the direct emission from activities controlled by Gothenburg Port Authority and scope 2 includes indirect emissions for Gothenburg Port Authority's electricity and district heating consumption.

The result for the total carbon footprint increases from 190 790 tonnes $CO_{2\text{-eq}}$ to 192 130 tonnes $CO_{2\text{-eq}}$. This generates an increase by nearly 1 % of the carbon footprint, including all scopes for Gothenburg Port Authority, see Figure 4-4.

[17] From the 22 reinvestment projects

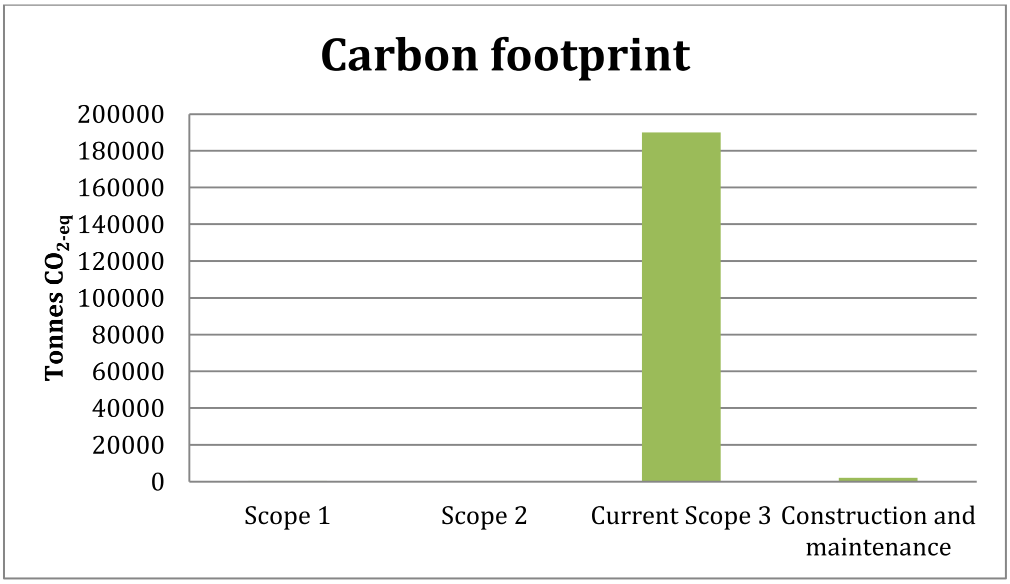

Figure 4-4. The result from the 22 construction and maintenance projects at the Port of Gothenburg during 2013, called here only "construction and maintenance". This is presented together with scope 1, scope 2 and current scope 3 for Gothenburg Port Authority from 2013. Scope 1 includes the direct emission from activities controlled by Gothenburg Port Authority and scope 2 includes indirect emissions for Gothenburg Port Authority's electricity and district heating consumption. Scope 3 includes the indirect emissions generated from especially vessels and loading fuels within the port area.

Based on the investments, the 22 construction and maintenance projects included in this thesis stands for 30 % of the total construction and maintenance related investments during 2013. If that is converted to emissions, the total $CO_{2\text{-eq}}$ emissions for all 160 projects can be estimated to be around 4500 tonnes $CO_{2\text{-eq}}$ in total during 2013 from construction and maintenance operations.

The uncertainty factor is set to 25 % for all emission factors and the result for the 22 construction and maintenance projects can therefore vary between 1100 to 1700 tonnes $CO_{2\text{-eq}}$ emissions emitted during 2013. The uncertainty for the total projects in the port during 2013 is probably even higher but if using the same uncertainty factor, the total carbon footprint range is between 3600-5600 tonnes $CO_{2\text{-eq}}$ emissions. This means up to a sevenfold increase of the total $CO_{2\text{-eq}}$ emissions for the 160 construction and maintenance projects compared to scope 1 and scope 2 for Gothenburg Port Authority, see Figure 4-5.

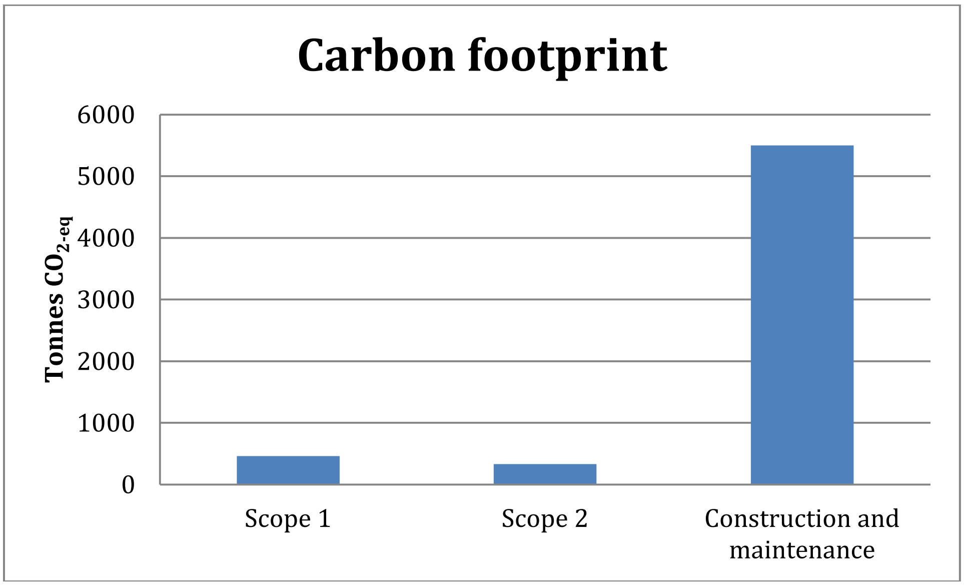

Figure 4-5. The result for the construction and maintenance projects including in a maximum "worst case scenario" for a carbon footprint for all 160 projects performed at the Port of Gothenburg during 2013. It is assumed that emissions are proportionally related to the cost. The emissions are compared with scope 1 and scope 2 from the same year calculated by Gothenburg Port Authority.

The highest value for the total carbon footprint, 5600 tonnes $CO_{2\text{-eq}}$, which represent all 160 projects during 2013, indicates an increase of 3 % of the total carbon footprint, see Figure 4-6.

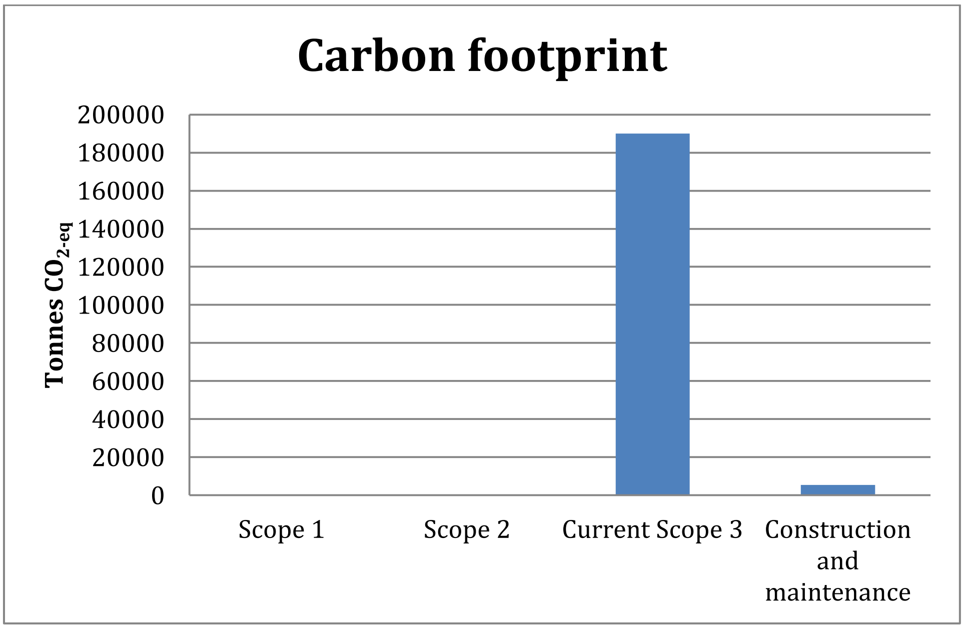

Figure 4-6. The result for the construction and maintenance projects including in a maximum "worst case scenario" for a carbon footprint for all 160 projects performed at the Port of Gothenburg during 2013. It is assumed that emissions are proportionally related to the cost. The emissions are compared with scope 1, scope 2 and current scope 3 from the same year calculated by Gothenburg Port Authority.

4.4 Gothenburg Port Authority's sustainable port construction and maintenance guidelines

The guidelines can be applied to all construction and maintenance projects performed by Gothenburg Port Authority. Several of the guidelines are also applied to Sweden. It is important to meet with the contractors to identify potential improvements of the guidelines and to include such measures in the procurement processes. Best available technology measures are preferable followed in all projects and a key factor is cooperation between the port, contractors and suppliers.

The guidelines are inspired by "Los Angeles Harbor Department Sustainable Construction Guidelines for Reducing Air Emissions", see Appendix III (Los Angeles Harbor Department, 2009), "Sustainable Engineering Design Guidelines", see Appendix IV (Los Angeles Harbor Department, 2009) and "UK Environmental Agency's carbon reduction tips" (UK Environmental Agency, 2012). The guidelines are presented in a random order independent on how the port should prioritise. Guidelines 1 to 7 is about fuels and potential reductions related. Guideline 8 is about handling the equipment in use. Guidelines 9 and 10 are about the materials used in construction and maintenance projects. Guidelines 11 and 12 are about the transportation in general to, from and within the port. Guidelines 13 to 15 are about reuse and recycling of used materials. Finally, guidelines 16 to 20 are about how to follow up emissions from the related activities and how to work to reduce them on a more strategic level.

Examples related to the guidelines are considered to be a further recommendation to investigate and therefore beyond the boundaries for this thesis. Neither specific numbers nor materials are restricted in the guidelines because of the possible development and interpret of the guidelines for the further work. It is thus important to consider the aspect of including several examples of actions under each guideline when implementing the guidelines in Gothenburg Port Authority environmental work.

Table 4-7. This is 20 suggestions for the guidelines on sustainable port construction and maintenance that can be used by Gothenburg Port Authority. Guidelines 1 to 7 is about fuels and potential reductions related. Guideline 8 is about handling the equipment in use. Guidelines 9 and 10 are about the materials used in construction and maintenance projects. Guidelines 11 and 12 are about the transportation in general to, from and within the port. Guidelines 13 to 15 are about reuse and recycling of used materials. Finally, guidelines 16 to 20 are about how to follow up emissions from the related activities and how to work to reduce them on a more strategic level.

Suggestions for Gothenburg Port Authority's sustainable port construction and maintenance guidelines	
Fuels	
1	Monitoring fuel or energy consumption in all vehicles and equipment.
2	Restrict idling of construction equipment and vehicles when not in use.
3	Maintain a minimum buffer zone between truck traffic and sensitive receptors[a].
4	Apply ecodriving for all vehicles to, from and within the port area.
5	Use electric power in favour of diesel power when available.
6	Use renewable fuels in favour of fossil fuels when available.
7	Apply a minimum emission reduction for all harbour craft with engines equivalent to the requirements from The Swedish Transport Administration.
Handling equipment	
8	Maintain equipment according to manufacturers' specifications, to sustain the quality and efficiency within the equipment.
Materials	
9	Substitute materials to less carbon intense materials or products when possible. The products should remain the same quality but have lower GHG emissions related to raw material extraction and production.
10	Focus on the materials with the highest contribution to the carbon footprint and minimise the need for the material without substituting it for a material of a similarly high impact.
General transportation	

11	Transport the important construction and maintenance material to the port site with vessels when possible, otherwise by train.
12	Reschedule construction activities that affect traffic flow, both vessels but also on road traffic, to the off-peak hours which extent practicable.
Reuse and recycling	
13	Use recycled material when possible.
14	Minimize the waste flow by reuse materials and equipment in other projects.
15	Leave the used material or equipment to a recycling facility.
Strategic level	
16	Demand suppliers for an approximately amount of used materials or fuels for each project as an appendix in complement to the invoice to make emission calculations easier.
17	Effective communication between the design team, contractors and procurement department to support efficient agreements.
18	Follow up emission calculations for construction and maintenance projects on a yearly basis.
19	Take part of the latest research and put pressure on the contractors to use environmentally labelled products.
20	Work in cross function teams to ensure the competence quality of both project work and environmental work.

a. A receptor is a living species which could be harmed, for example the human health, water resources or ecotoxicity in the environment.

5. Discussion

The discussion focuses on the four objectives in this thesis. The chapter starts with a discussion about mapping ports and what other ports can duplicate. The discussion continues with the carbon footprint method including possible improvements of the method. Then the results are discussed with focus on the quantities of emissions calculated. The discussion continues with how to reduce emissions in construction and maintenance projects at the Port of Gothenburg and ends with a discussion about the development of guidelines.

5.1 About mapping ports

Since no other port or organisation has calculated a carbon footprint on the infrastructure of a port, this report can serve as a first step towards emission estimations from such areas and related activities. The initial objective with mapping was to evaluate the work of emission calculation from construction and maintenance in port areas. Since this was not achieved from any port, the mapping leads instead to a broader foundation of what actions a port can take to reduce emissions. Ports around the world have the same problem in terms of $CO_{2\text{-eq}}$ emissions. Knowledge and experience can therefore be shared. Mapping ports has been done before as a benchmarking for example (Climeport, 2010), and is a good way of showing transparency and learn from others.

Another aspect comprised is the financial framework including funding, subsidies and investments. Ports have different possibilities when working with emission reduction actions depending on the financial situation. The investments could also be related to the "social cost of carbon" meaning the money saved from avoided damage. This could be used by the ports to estimate how much to invest in emission reductions, but is not calculated in this report.

Gothenburg Port Authority has worked with emission reduction on several levels and by different applications. All ports included in the mapping have launched a sustainability or environmental report, which is a good way of communicating knowledge and activities related to environmental protection. Some of the emission reduction actions are also similar between the ports. One example is solar power that all ports in the mapping have installed except the Port of Gothenburg. On the other hand, the Port of Gothenburg uses environmentally labelled electricity, which Sweden can offer easily. Gothenburg Port Authority's constructors are generally using diesel consuming equipment and vehicles, which can be swift to electrical vehicles with retained quality. Other good examples of emission reduction actions are to implement ecodriving, both for vehicles on and off roads but also for vessels. It can also be to use biofuels instead of fossil fuels.

The four ports have different environmental targets because they have different qualifications and work methods. A suggestion for the $CO_{2\text{-eq}}$ reduction target is to set up both near term targets but also long terms and work with both in parallel to ensure that the reduction targets will be met.

The mapping method used in this thesis provides an overview of all four ports but does not cover a deeper knowledge for comparison between the ports. The four ports selected for the mapping have almost the same layout for their environmental work and the environmental or sustainability reports are quite similar. The result in the mapping could differ if other ports were chosen and if they have not presented their environmental work in a similar way. If more ports' emission reduction actions are included in the mapping result, more experience can be exchanged between all involved. Generally, the environmental and sustainability reports highlight the improvements in environmental work more than the failures. Also, in some reports, there are lack of transparency on how the emissions are calculated and which assumptions attained. This is mostly because the reports often are produced for external communication purposes. A recommendation is that ports also produce a more extensive report for research purposes or evaluation. Another is that external verifications should be made on all emission calculations to verify the numbers and the underlying work. Other ports that have not started their environmental work or want to increase alternatives in emission reduction actions can learn from the mapping and as an outcome produce reports with high levels of transparency. This makes further actions easier to implement and follow up.

5.2 Improvements of the carbon footprint standard

The carbon footprint standard is a straightforward method with a result highly dependent on the emission factors, which was the selected model in this thesis. A carbon footprint assessment is suitable for both internal and external communication. The carbon footprint can be used to lower energy cost, engaging employees, optimising processes and projects. The information gathered in a carbon footprint assessment can also support the suppliers to reduce their emissions and thereby reducing the footprint from construction and maintenance projects. The carbon footprint for port provides information to the customer. As many products come across the Port of Gothenburg, the carbon footprint calculated for the port could also be allocated and included in many product chains. This also reduces time and cost for customers, which desire to calculate the carbon footprint for a product passing the port.

The quality of the result in a carbon footprint could be improved by using site production specific emission factors. To develop such specific emission factors, time is needed and the results will probably be within the range giving by the current uncertainty factor. To make the result more adequate, a sensitivity analysis including uncertainty factors in the carbon footprint could be done. The results in this report are only indicative and not exact because of the generally chosen emission factors, the uncertainty factor. The boundaries related are to some extent an incomplete collection of used materials and energy related products. This is because the emission factors are implied, which means the values are general and includes assumptions. The assumptions could be about the rate of recycled amounts used in production or for example where the production takes place. The uncertainty factor is also assumed to 25 % and if it changes, the result for the carbon footprint assessment will differ. The result will also differ if all rented equipment, such as scaffolds and hammers were included. The emissions from the rented products can be divided with their lifetime and allocated based on the number of days in use at the Port of Gothenburg during 2013 in the 22 construction and maintenance projects. If including this type of calculations it will increase the emissions in the carbon footprint.

Since no carbon footprint has been done for ports' infrastructure before, an emission factor data base for commonly used materials, equipment and vehicles in the port environment could be established. The materials and equipment used within the port need to meet the port's requirements. This can generate a difference compared to the average materials included in this report for emission factors applied to Sweden and especially road constructions. One alternative is to make a specific database for Sweden but it might be more adequate to summaries it into port activities for the northern region or EU. This means more ports could conduct emission calculations more easily for construction and maintenance operations.

As already mentioned, the most important is not the quantity of $CO_{2\text{-eq}}$ emissions in the carbon footprint in this early stage of calculating $CO_{2\text{-eq}}$ emissions in construction and maintenance projects. It is instead the knowledge from working with calculations in general. The aim of reducing emissions is easier to achieve if there is visible numbers to work with. It is important to follow up emissions to be able to compare the yearly levels of emissions and to verify reductions and other trends. To be able to do that, it is more adequate to simplify the calculations and make reasonable assumptions in order to have time and budget for the environmental work. This can be accomplished in a prepared and organised model. The key factors are instead to be consequent and to get a deeper knowledge and a wider perspective on how the port could take responsibility for their direct and indirect emissions and make reasonable reduction targets.

The specific source or origin of the materials is not included in the emission factors. The factors include average assumptions of where the materials are produced and the manufacturing could differ between different countries. The production is thus quite similar since the materials are well known and have been produced during a long period. The electricity grid mix and the fuel used for production could thus differ. Even if Gothenburg Port Authority has low emissions related to a product or service, it could in reality be higher depending on the material source. Since this study uses average values, it is not possible to state if the results for emissions from the construction and maintenance operations in Port of Gothenburg are reasonable or not.

Since the values for emission factors used in this thesis often are updated on a yearly basis, or at least evaluated, the result with identical projects next year will give another result. Also when and where the emission factors are collected or calculated influence the values and the carbon footprint result. One argument could be that a carbon footprint assessment only shows today's emissions and not tomorrow's. That is true since emission factors and technologies constantly changes, but conclusions from this thesis presents the opposite at the same time. By calculating emissions today, makes the companies and society aware of the impact they causes and show where possible actions can take place, i.e. on energy-intensive products or activities.

5.3 The $CO_{2\text{-eq}}$ emissions result

It is important to mention that only 22 construction and maintenance projects out of approximately 160 projects during 2013 are included in the carbon footprint assessment in this report. The actual carbon footprint is therefore higher than the one presented in this report. The remaining projects in construction and maintenance operations emit $CO_{2\text{-eq}}$ emissions. That the remaining projects stand for approximately 70 % of the emissions is only based on the related cost. To save time, this could be an acceptable rough estimation, especially if the emissions could be related to the cost. The assumption can be used years after a more complete calculation for all projects have been done during some years. If the relationship between cost and emissions are proportional, the estimated methodology could be used more frequently. Currently, the most costly part in a project is the project managers and the constructors, which make the uncertainty even higher for the amount of used materials and energy related to only cost.

To make the calculations easier for the ports, a compulsory appendix together with for example the contracts, invoices or procurement documents should be included. The appendix can for example involve the mass of used material and energy related products specified as in Table 4-5. This makes the calculations easier to perform for the port and the mass of used materials and volumes of energy related products give the suppliers and contractors a better overview and relation to their customers, e.g. the ports. The appendix can also be extended and include several activities and more complex materials used in construction and maintenance projects.

The increase by nearly 1 % of the total carbon footprint from the 22 reinvestment projects might not seems to be much compared to the total current carbon footprint for Gothenburg Port Authority. It is thus important to highlight that construction and maintenance is only one category of indirect emissions in scope 3. See Section 2.2 for more included categories that have not been calculated.

5.4 Emission reduction in construction and maintenance operations

There are especially two general different strategies on how to reduce environmental impact from flows of materials and energy (Holmberg, J., 1999). The first is called dematerialisation, which means increase in service exchange from a product. The product can for example last longer or be used more efficiently. The second strategy is called transmaterialisation, which means the current product could be substitute with another product less harmful or with less environmental impact. There are also different additional methods related to the two strategies. One method is to direct minimise the use of the product. This means minimise the material and energy flows related to a specific product. Another is to reuse or recycle the product, which will result in a reduction in the raw material inflow for producing the product and a reduced waste flow. As an example, the Port of Gothenburg uses the end of life concrete and crushes it into small pieces and used in filling areas, such as holes, within the port area. This concept can only continue during a time specific period and therefore a more suitable purpose needs to be found for the large volumes of end of life concrete. It is important to remember that the port always has to pay for recycling materials, but if this changes in the future, there could also be a revenue and therefore easier to achieve and work with for several materials.

The most difficult issue is to determine who has the responsibility for the emissions from construction and maintenance projects. The emissions from the port are included in scope 3 and therefore in scope 1 in another company, i.e. the suppliers. Do the suppliers alone have the responsibility to reduce the emissions from their production? Well, if Gothenburg Port Authority includes the reduction target and transparency of emissions related to a product in their procurement work, it would force suppliers to work towards reduction. Another solution for $CO_{2\text{-eq}}$ emission reduction is to implement policies or subsidies (Azar, C., 2003). Sweden can continue to increase the cost of emitting $CO_{2\text{-eq}}$, introduce or develop subsidies implemented for avoid emissions or find other solutions more energy intense. This can generate lower emissions and/or progress the fuel shift to renewable fuels, e.g. biofuels. It is not the Port of Gothenburg's responsibility to implement policies but if they are clear in their arguments together with other companies, the Swedish government might consider implementing stricter regulations and reduction targets. The government is responsible for providing information, establish policy and legal frameworks and give financial support for those who are willing and already work with environmental protection and emission reductions (IPCC, 2014).

In general, if mixing and increasing the complexity of materials in products, the quality can increase and the products last longer (Karlsson, S. & Holmberg, J., 2004). This could also minimise the amount of material needed. It is possible that emissions from rarely used materials will become lower if the demand increases. A higher production rate generally benefits energy efficiency improvements, lower costs and also lower emissions. Ports also need to work towards sustainable consumption in the construction and maintenance projects. Sustainable consumption is not only about consuming less, it is about consuming different and more efficiently (Jackson & Michaelis, 2003). Consumption is often closely linked to environmental impacts and resource use.

5.4.1 Diesel and gasoline

One substitution for diesel and gasoline could be biofuels. By using some types of biofuels, a reduction of up to 50-80 % of the $CO_{2\text{-eq}}$ emissions can be accomplished (The Swedish knowledge centre for renewable transportation fuels, 2013; Preem, 2012; International Energy Agency, 2004). If low-emitting biofuels are implemented, a reduction of at least 500 tonnes of $CO_{2\text{-eq}}$ emissions could be achieved for the 22 construction and maintenance projects, which corresponds to more than one third of the total $CO_{2\text{-eq}}$ emissions. The implementation of biofuels can also improve energy security, reduce other pollutants and improve vehicle performance.

There are different drawbacks with biofuels and the main argument is the land areas required for growth of crops used in the production of biofuels, which also generates emissions. The main reason why not using biofuels today is the cost issue. The production cost of for example ethanol and biodiesel is higher than of gasoline and diesel (The Swedish knowledge centre for renewable transportation fuels, 2013). Another argument is the lack of accessibility for renewable fuels at some filling stations. In Sweden another concept is implemented for fossil fuels, which is that they are mixed with renewable fuels to increase the function and make the transition towards renewable fuels more flexible. Therefore, the used emission factor in this report for diesel and gasoline are general and only including average mix of fossil fuels and renewables. If the contractors used another fuel than the most common the vehicles or equipment, the result will differ.

5.4.2 Concrete

There is a relatively large difference in the use of energy per tonne of concrete produced in different countries. The most energy demanding step is the production of cement. The main reason for the differences in energy use is the difference in energy efficiency equipment. Studies have shown that the global potential for $CO_{2\text{-eq}}$ emission reduction in cement production is estimated to be at least 5% and up to 20 % of the total $CO_{2\text{-eq}}$ emissions (Worrel, E., 2004). There is research claiming that concrete can take up CO_2 during its lifetime. One study is applied for Sweden and it indicates an uptake that corresponds to 17 % of the CO_2 emissions generated from the total production of new cement in Sweden. The carbon footprint for concrete will significantly differ if this is included in the calculations (Andersson, R. el al., 2013).

The emission factor for concrete does not include any cement replacement. According to Östfjord[18], it is possible to replace cement in concrete with for example fly ash or sludge.

[18] Stig Östfjord, consultant at the Port of Gothenburg – concrete expert, personal communication 21 May 2014.

Since cement production is energy-intensive, the emissions related to concrete can decrease if cement is substituted with other alternatives. This is not done today since the quality and properties for concrete in a port is very strict and important. If new solutions are developed, replacement for large amounts of cement can be done.

5.4.3 Steel and plastics

To reduce $CO_{2\text{-eq}}$ emissions from steel, fuel switching and efficiency improvements have to be made in the steel manufacturing facilities, which all have different energy use profiles (Ruth M. 2004). The manufacture process still uses large amount of fossil fuels. Another option is to increase the amount of recycled steel, which has been done during the last years but it can increase further.

Plastics are not one of the major contributors to $CO_{2\text{-eq}}$ emissions in this study but might be a substitution material to for example steel in the future and the share of $CO_{2\text{-eq}}$ emissions could then rise. It might be possible to replace energy-intense plastics with modified bulk polymers, which are more energy efficient to produce (Patel, M. & Mutha, N., 2004). Plastics often higher emission factors than general steel but lower than for stainless steel. If plastics will substitute steel, the preferable option is therefore stainless steel.

5.4.4 Electricity

Due to the emission factors, the electricity emits less than 1 % $CO_{2\text{-eq}}$ per kWh than per litre fossil fuel. If compared based on energy content instead, 1 kWh corresponds to 3.6 MJ and one litre of fossil fuel (gasoline or diesel) contains 32 to 36 MJ per litre (European Commission, 2014). This means that average Swedish electricity with the emission factor of approximately 0.02 kg $CO_{2\text{-eq}}$ per kWh generate the same amount of energy (in MJ) as one litre diesel when emitting 0.18 kg $CO_{2\text{-eq.}}$ Compared to one litre fossil fuel, it emits 3 kg $CO_{2\text{-eq}}$. Environmental labelled electricity only emits 0.009 kg $CO_{2\text{-eq}}$ compared to the energy content as in one litre fossil fuel. If the port will shift to electrical equipment, and the equipment needs the same amount of energy in MJ as in corresponding diesel equipment, environmentally labelled should be chosen if possible. The average Swedish electricity mix is also preferable but only with such low emission factor, therefore the recommendation only apply to Sweden.

If all fossil fuels are substituted with average Swedish electricity mix, the emissions will decrease from nearly 900 tonnes $CO_{2\text{-eq}}$ to 50 tonnes $CO_{2\text{-eq}}$ from construction and maintenance reinvestment projects during 2013. The drawbacks with electricity could be the dependence on always having access to electricity while fuel could be stored. There are several problems related to a possible future electrification of Sweden. Even an electrification of only the Port of Gothenburg can be difficult. The intermittency problem can be an issue. The advantages with electricity besides emission reduction are that no emissions occur in the working surrounding and the noise is often lower compared to using fossil fuel vehicles or equipment.

5.5 Development of Guidelines

The guidelines that are developed and suggested in this thesis are not specific. They are for example not expressed in terms of numbers and time targets. This is a conscious decision. The guidelines have to serve for a long time, including improvement and development of them, and they have to be understandable from the whole corporations' perspective. Since a port is a very complex system, more guidelines on how to work for emission reduction are possible to develop. The guidelines should be short and compact to increase opportunity of being used. If there would be more guidelines added, there is a risk to experience that it is no idea to work with them because they are too complex. The guidelines should be easy to use, follow up and give satisfactory results for the port.

The main reason why guidelines sometimes are ignored is because of the cost related to improve efficiency and the time needed for gathering information (Brown, M., 2004). The emission reduction might not seem to be high on an individual basis for the 22 reinvestments projects. This do not have to be accurate since the potential of materials and energy saving can be important when summed together from all suppliers and consumers. The total emissions can be significantly higher if adding all emissions from the 160 projects and including the uncertainty factors.

There must be a change in the information from the suppliers and in the procurement methodology. The suppliers have to take the fully responsible for their product and estimate the emission related. It is also important to sustain a dialog between the port and suppliers for understanding the suppliers' or producers' challenges and difficulties in the work towards emission reduction.

The guidelines and reduction targets for the ports should follow the backcasting concept. In backcasting, the guidelines are based on a description for the restrictions and possibilities in a future situation. In contrast to backcasting is the traditional forecasting, where a description of current trends is used based on previous results and trends (Holmberg, J., 1999).

The guidelines are applied to the Port of Gothenburg but could also be used for other international ports and by similar industries. If Gothenburg Port Authority wants to reach their climate target and remains their emissions from all scopes to 190 000 tonnes $CO_{2\text{-eq}}$ by 2016, the authority can use the guidelines as a base. The further development and implementation of the guidelines are Gothenburg Port Authority's responsibility.

6. Conclusions

Since no other ports have included calculations for their infrastructure for several reasons, a method needs to be established, developed and implemented. This report serves as a foundation or inspiration for further development of $CO_{2\text{-eq}}$ calculations for construction and maintenance projects in a port. The method for calculations as well as the guidelines can be applied for several ports' infrastructure. The carbon footprint assessment identifies hotspots, which means identification of materials and energy related products that contribute to the majority of $CO_{2\text{-eq}}$ emissions. It is possible to compare the total material and energy use and the emission loads related from construction and maintenance projects.

The material and energy related product that contribute the most to $CO_{2\text{-eq}}$ emissions in this thesis are fossil fuels and concrete. The exact numbers of $CO_{2\text{-eq}}$ emissions from fossil fuels and concrete are highly dependent on the emission factors. An extraordinary high amount of concrete and large volumes of fossil fuels are used, compared to other analysed posts. A conclusion is that they stand for the highest emissions in construction and maintenance projects during a typically year at the Port of Gothenburg.

For port construction and maintenance operation activities there are many different technologies and environmental management solution used internationally, each with practices and actions that other ports could learn from. Independent on the ports' size and service, all ports should work with emission reductions since it is often located near cities, in sensitive areas and handle a lot of goods. In addition, some vessels and products are freighted between several ports and therefore it is important that ports work together in a network. The work towards environmental protection and emission reduction can be established in a common organisation or project, as for example the EcoPort project, and be applied for several ports and activities.

One reason for emitting $CO_{2\text{-eq}}$ is because it is related to cost. Fossil fuels are currently cheaper than renewable fuels. This may however, change in future when more cost-effective biofuels are expected to enter the market and/or cost for emitting GHG emissions are increasing, e.g. by carbon taxes. Concrete is a reliable material and are still used for its properties and it is costly and time consuming to shift material. Gothenburg Port Authority could work on minimising their emissions included in the different scopes but the port might need support from an external sources. The contractors and suppliers need pressure not only from Gothenburg Port Authority but also from the Swedish government.

A general conclusion is that Gothenburg Port Authority needs to work towards sustainable consumption in the construction and maintenance projects. One key factor to success is to work in cross function teams where different knowledge and experience cooperate and make the emission reduction even more efficient. The team members working with emission reduction from construction and maintenance should preferable be represented from the Environmental Department, Infrastructure Department, Procurement Department at Gothenburg Port Authority and the main contractors. Also regulatory information from manufactures and experts are necessary as well as information about emissions related to current and new technologies and materials. As mentioned in the guidelines, Gothenburg Port Authority should demand suppliers for an approximately amount of used materials or fuels for each project as an appendix in complement to the invoice to make emission calculations easier.

7. Further recommendations

One of the further recommendations is to include more indicators than GWP as included in a carbon footprint assessment. This means for example to estimate emissions such as SO_2, which can be related to acidification, to generate a more comprehensive result about what is emitted from the port operations. A further performance is to do weighting between the indicators to get a comprehensive perspective on the environmental impacts. In the carbon footprint, the local impacts are not visible which is important in such sensitive areas as the Port of Gothenburg.

This report does not include the disposal or waste management step in the life cycle of a product or project. The materials can for example be transported to landfill or an incineration plant, which generate an environmental impact in most cases. The incineration could also generate energy savings from material recovery. In the future, it would be good to include the whole life cycle and consider alternatives on how to treat the materials when disposed or recycled.

Another recommendation is to continue develop the guidelines and set stricter approaches to achieve lower emissions from construction and maintenance operations. This is a flexible way to incorporate $CO_{2\text{-eq}}$ emission reduction in a port company. The 20 guidelines suggested in this thesis can have several examples that can be done to lower emissions in each guideline. These examples are considered to be a further recommendation to find, evaluate and implement.

A further evaluation about the possibility to use other materials and substitute the most contributing materials and fuels would be beneficial. A sensitivity analysis could be another option for developing the evaluation of the carbon footprint result even further, since the uncertainty is an estimation made in this report and rather high values has been chosen. It is thus more sufficient to calculate the approximately emissions from port operations included in scope 3, which is not included in the current carbon footprint for Gothenburg Port Authority. It will ensure a more complete carbon footprint assessment as well as a possible development of the knowledge and work towards emission reductions. Finally, it is recommended that ports establish measurements for emission reductions, both internal and external, and follow up the work to determine the trends in material and energy savings related to different actions.

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Appendix

Appendix I – Global Warming Potential

Appendix II – Gothenburg Port Authority's emission scopes

Appendix III - Sustainable Construction Guidelines

Appendix IV- Sustainable Engineering Design Guidelines

Appendix V - Overview of the 22 construction and maintenance projects

Appendix I – Global Warming Potential

Global warming potentials, expressed in characterisation factors for time horizon 100 years relative to CO_2 (IPCC, 2007).

Industrial designation	Chemical formula	Characterisation factors for GWP100
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298
Substances controlled by the Montreal Protocol		
CFC-11	CCl_3F	4 750
CFC-12	CCl_2F_2	10 900
CFC-13	$CClF_3$	14 400
CFC-113	CCl_2FCClF_2	6 130
CFC-114	$CClF_2CClF_2$	10 000
CFC-115	$CClF_2CF_3$	7 370
Halon-1301	$CBrF_3$	7 140
Halon-1211	$CBrClF_2$	1 890
Halon-2402	$CBrF_2CBrF_2$	1 640
Carbon tetrachloride	CCl_4	1 400
Methyl bromide	CH_3Br	5
Methyl chloroform	CH_3CCl_3	146
HCFC-22	$CHClF_2$	1 810
HCFC-123	$CHCl_2CF_3$	77
HCFC-124	$CHClFCF_3$	609
HCFC-141b	CH_3CCl_2F	725
HCFC-142b	CH_3CClF_2	2 310
HCFC-225ca	$CHCl_2CF_2CF_3$	122
HCFC-225cb	$CHClFCF_2CClF_2$	595
Hydrofluorocarbons		
HFC-23	CHF_3	14 800
HFC-32	CH_2F_2	675
HFC-125	CHF_2CF_3	3 500
HFC-134a	CH_2FCF_3	1 430
HFC-143a	CH_3CF_3	4 470
HFC-152a	CH_3CHF_2	124
HFC-227ea	CF_3CHFCF_3	3 220
HFC-236fa	$CF_3CH_2CF_3$	9 810

HFC-245fa	$CHF_2CH_2CF_3$	1 030
HFC-365mfc	$CH_3CF_2CH_2CF_3$	794
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1 640
Perfluorinated compounds		
Sulphur hexafluoride	SF_6	22 800
Nitrogen trifluoride	NF_3	17 200
PFC-14	CF_4	7 390
PFC-116	C_2F_6	12 200
PFC-218	C_3F_8	8 830
PFC-318	$c\text{-}C_4F_8$	10 300
PFC-3-1-10	C_4F_{10}	8 860
PFC-4-1-12	C_5F_{12}	9 160
PFC-5-1-14	C_6F_{14}	9 300
PFC-9-1-18	$C_{10}F_{18}$	>7 500
Trifluoromethyl sulphur pentafluoride	SF_5CF_3	17 700
Fluorinated ethers		
HFE-125	CHF_2OCF_3	14 900
HFE-134	CHF_2OCHF_2	6 320
HFE-143a	CH_3OCF_3	756
HCFE-235da2	$CHF_2OCHClCF_3$	350
HFE-245cb2	$CH_3OCF_2CHF_2$	708
HFE-245fa2	$CHF_2OCH_2CF_3$	659
HFE-254cb2	$CH_3OCF_2CHF_2$	359
HFE-347mcc3	$CH_3OCF_2CF_2CF_3$	575
HFE-347pcf2	$CHF_2CF_2OCH_2CF_3$	580
HFE-356pcc3	$CH_3OCF_2CF_2CHF_2$	110
HFE-449sl (HFE-7100)	$C_4F_9OCH_3$	297
HFE-569sf2 (HFE-7200)	$C_4F_9OC_2H_5$	59
HFE-43-10pccc124 (H-Galden 1040x)	$CHF_2OCF_2OC_2F_4OCHF_2$	1 870
HFE-236ca12 (HG-10)	$CHF_2OCF_2OCHF_2$	2 800
HFE-338pcc13 (HG-01)	$CHF_2OCF_2CF_2OCHF_2$	1 500
Perfluoropolyethers		
PFPMIE	$CF_3OCF(CF_3)CF_2OCF_2OCF_3$	10 300
Hydrocarbons and other compounds – Direct Effects		
Dimethyl ether	CH_3OCH_3	1
Methylene chloride	CH_2Cl_2	8.7
Methyl chloride	CH_3Cl	13

Appendix II – Gothenburg Port Authority's emission scopes

Gothenburg Port Authority calculates and assesses different activities in their carbon footprint (Gothenburg Port Authority, 2012). They have included all activities defined in scope 1 and scope 2 in the GHG Protocol (2011). In scope 3, Gothenburg Port Authority has included some activities listed below.

Direct emissions (scope 1)
The following activities are part of Gothenburg Port Authority scope 1 – direct emissions:
1. Operational vessels: MS/hamnen and "Saxkranen"
2. Operational vehicles: Operations, Security, Infrastructure
3. Heating (gas) of owned buildings
4. Fire equipment - Torshamnen

Energy indirect emissions (scope 2)
The following activities are part of Gothenburg Port Authority scope 2 – indirect emissions:
1. Electricity by owned operations (buildings and public lighting)
2. Electricity used by tenants using our buildings
3. District heating by owned operations (buildings, pipes in the Oil terminal)

Other indirect emissions identified and reported (scope 3)
The following activities are part of Gothenburg Port Authority scope 3 – other indirect emissions:
1. Business flights Gothenburg Port Authority
2. Business travel by own cars Gothenburg Port Authority
3. APM Terminals Gothenburg AB (their scope 1+2)
4. Älvsborg Ro/ro AB (their scope 1+2)
5. Logent Ports & Terminals AB (their scope 1+2)
6. Vessels at the quay and within the municipality boundary
7. Loading of gasoline, leakage of pipelines (VOC)

Appendix III - Sustainable Construction Guidelines

In March 2008, the Port of Los Angeles adopted the Sustainable Construction Guidelines to support the port's Green Building Policy (Los Angeles Harbor Department, 2009). The guidelines promote objectives pertaining to emission reduction, construction training and efficiency, air quality, noise, habitat preservation, safety, and waste reduction. The Sustainable Construction Guidelines are still under development. The draft guidelines include:

(1) Develop and implement sustainable construction training
(2) Develop Sustainable Construction Report prior to commencement of the project
(3) Implement a Sustainability Inspection Program
(4) Configure construction scheduling and sequencing to reduce unnecessary lag time between materials deliveries and actual usage at the site
(5) Reduce the amount of paperwork associated with the construction administration
(6) Prevent siltation and sedimentation of down gradient sites and receiving waters
(7) Provide dust control
(8) Prevent storm water pollution during construction
(9) Minimize disturbance of soil and vegetation during construction
(10) Reduce indoor air quality problems
(11) Develop acoustical control measures to reduce noise levels
(12) Provide the construction team with health and safety management, hazard awareness, prevention techniques, and a health & safe atmosphere
(13) Salvage construction materials and wastes to reduce demand for virgin materials

Appendix IV- Sustainable Engineering Design Guidelines

In 2008 the Port of Los Angeles initiated development of the Sustainable Engineering Design Guidelines (Los Angeles Harbor Department, 2009). The Sustainable Engineering Design Guidelines are still under development. The draft guidelines include such provisions as:

(1) Engage all appropriate stakeholders in an initial sustainability project planning meeting
(2) Continue to involve stakeholders in regular project progress meetings
(3) Develop sustainable project deliverables by using fewer resources, such as creating awareness of sustainability through the use of recycled and bleach-free paper
(4) Use fewer resources through the use of double-sided printing
(5) When possible, use electronic submissions of bids, plans, specifications, and associated planning, design, and construction documents and invoices
(6) Have electronic meetings to reduce the use of fossil fuels associated with vehicles used to travel to meetings
(7) Incorporate principles from the LEED rating system that promote energy and water conservation measures.

Appendix V - Overview of the 22 construction and maintenance projects

Different types of materials and its emission factor, associated CO_{2-eq} emissions and volume/amount used						
Material	**Emission factor**	**Unit**	**Total emissions**	**Unit**	**Amount**	**Unit**
Acidproof stainless steel	4.5	kg CO_{2-eq} /kg	329	kg CO_{2-eq}	73	kg
ACP Evolution Diesel	2.72	kg CO_{2-eq} /l	359	kg CO_{2-eq}	132	litre
Alkylate gasoline	2.13	kg CO_{2-eq} /l	96	kg CO_{2-eq}	45	litre
Alloy Steel	6.5	kg CO_{2-eq}/kg	85	kg CO_{2-eq}	13	kg
Aluminium	8.4	kg CO_{2-eq} /kg	370	kg CO_{2-eq}	44	kg
Asphalt	0.051	kg CO_{2-eq} /kg	4019	kg CO_{2-eq}	78800	kg
Blank galvanised harden steel	2.0	kg CO_{2-eq} /kg	192	kg CO_{2-eq}	96	kg
Blank galvanised carbon steel	1.87	kg CO_{2-eq} /kg	103	kg CO_{2-eq}	55	kg
Blank galvanised stainless steel	6.87	kg CO_{2-eq} /kg	227	kg CO_{2-eq}	33	kg
Bulldozer	48.1	kg CO_{2-eq} /h	113901	kg CO_{2-eq}	2368	h
Cement	0.715	kg CO_{2-eq} /kg	4326	kg CO_{2-eq}	6050	kg
Composite material	57	kg CO_{2-eq} /kg	13110	kg CO_{2-eq}	230	kg
Compreg wood	6.8	kg CO_{2-eq} /m^3	3	kg CO_{2-eq}	0.4	m^3
Compressor	107.3	kg CO_{2-eq} /h	858	kg CO_{2-eq}	8	h
Concrete	0.153	kg CO_{2-eq} /kg	133574	kg CO_{2-eq}	873030	kg
Concrete pump	0.9	kg CO_{2-eq} /m^3	1013	kg CO_{2-eq}	1125	m^3
Crane	59.5	kg CO_{2-eq} /h	35224	kg CO_{2-eq}	592	h
Crude steel	1.5	kg CO_{2-eq} /kg	30	kg CO_{2-eq}	20	kg

Diesel	2.98	kg $CO_{2\text{-}eq}$ /l	2271	kg $CO_{2\text{-}eq}$	762	litre
E-coated steel	6.87	kg $CO_{2\text{-}eq}$ /kg	433	kg $CO_{2\text{-}eq}$	63	kg
Electricity, Swedish average mix	0.02	kg $CO_{2\text{-}eq}$ /kWh	1126	kg $CO_{2\text{-}eq}$	56301	kWh
Environmental labelled electricity	0.001	kg $CO_{2\text{-}eq}$ /kWh	4	kg $CO_{2\text{-}eq}$	3849	kWh
Excavating machine	26.9	kg $CO_{2\text{-}eq}$ /h	11594	kg $CO_{2\text{-}eq}$	431	h
Galvanised iron	2.41	kg $CO_{2\text{-}eq}$ /kg	7548	kg $CO_{2\text{-}eq}$	3132	kg
Gasoline 95 okt	2.67	kg $CO_{2\text{-}eq}$ /l	937	kg $CO_{2\text{-}eq}$	351	litre
Galvanized stainless steel	6.87	kg $CO_{2\text{-}eq}$ /kg	3291	kg $CO_{2\text{-}eq}$	479	kg
Galvanized steel	1.87	kg $CO_{2\text{-}eq}$ /kg	1640	kg $CO_{2\text{-}eq}$	877	kg
Glass Reinforced Plastic	8.1	kg $CO_{2\text{-}eq}$ /kg	608	kg $CO_{2\text{-}eq}$	75	kg
Harden spring-steel	2	kg $CO_{2\text{-}eq}$ /kg	72	kg $CO_{2\text{-}eq}$	36	kg
Harden steel	2	kg $CO_{2\text{-}eq}$ /kg	84	kg $CO_{2\text{-}eq}$	42	kg
Heavy truck	71.5	kg $CO_{2\text{-}eq}$ /h	11086	kg $CO_{2\text{-}eq}$	155	h
Iron	2.03	kg $CO_{2\text{-}eq}$ /kg	102	kg $CO_{2\text{-}eq}$	50	kg
Jet cutting (diesel)	119.2	kg $CO_{2\text{-}eq}$ /h	627409	kg $CO_{2\text{-}eq}$	210540	litre
Jet cutting (electricity)	0.2	kg $CO_{2\text{-}eq}$ /h	1053	kg $CO_{2\text{-}eq}$	52635	kWh
Light truck/Pickup	7.2	kg $CO_{2\text{-}eq}$ /h	91519	kg $CO_{2\text{-}eq}$	12711	h
Local Wind Electricity	0.01	kg $CO_{2\text{-}eq}$ /kWh	521	kg $CO_{2\text{-}eq}$	52076	kWh
Paper	0.52	kg $CO_{2\text{-}eq}$ /kg	41	kg $CO_{2\text{-}eq}$	78	kg
Plywood	584	kg $CO_{2\text{-}eq}$ /m^3	4672	kg $CO_{2\text{-}eq}$	8	m^3
Polyester	2.7	kg $CO_{2\text{-}eq}$ /kg	57	kg $CO_{2\text{-}eq}$	21	kg
Polyethene	2.5	kg $CO_{2\text{-}eq}$ /kg	1970	kg $CO_{2\text{-}eq}$	788	kg
Polypropylene	1.98	kg $CO_{2\text{-}eq}$ /kg	252	kg $CO_{2\text{-}eq}$	127	kg

Polystyrene	3.38	kg CO_{2-eq} /kg	3009	kg CO_{2-eq}	890	kg
PVC plastics	3	kg CO_{2-eq} /kg	600	kg CO_{2-eq}	200	kg
Reinforcement steel	0.72	kg CO_{2-eq} /kg	13306	kg CO_{2-eq}	18481	kg
Rubber	2.85	kg CO_{2-eq} /kg	1263	kg CO_{2-eq}	443	kg
Stainless steel	6.5	kg CO_{2-eq} /kg	225856	kg CO_{2-eq}	34747	kg
Swedish wood	59.2	kg CO_{2-eq} /m^3	3078	kg CO_{2-eq}	52	m^3
Untreated steel	1.5	kg CO_{2-eq} /kg	8675	kg CO_{2-eq}	5783	kg
Yellow galvanized steel	1.83	kg CO_{2-eq} /kg	4	kg CO_{2-eq}	2	kg
Zink	1.72	kg CO_{2-eq} /kg	4028	kg CO_{2-eq}	2342	kg
TOTAL			**1336**	**tonnes CO_{2eq}**	**1060**	**tonnes**[19]

[19] Excluding fuels and electricity, the volume for the wood related products in m^3 is recalculated, using the density 550 kg/m3 (UK Environmental Agency, 2012).